PRODUCTIVITY OF FOUR FODDER TREE SPECIES, THEIR NUTRITIONAL VALUE AND POTENTIAL ROLE IN RUMINANT PRODUCTION IN EASTERN BOTSWANA

By

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature…….. Date……

ABSTRACT

Sustainable livestock production in semi-arid Botswana could be improved through tree planting on-farm to provide much needed protein and shade. Such action can be encouraged if the growth, productivity, nutritional value of trees and their contribution to mass gain of livestock are known.. A study at Malotwana investigated two indigenous species, *Acacia galpinii* and *Faidherbia albida,* and two exotic species, *Leucaena diversifolia* and *L. leucocephala,* at three spacings in a randomised complete block design replicated five times. The three spacings represented 400, 317 and 241 trees per hectare. The study was conducted over 6.5 years. Indigenous trees were sampled biennially and exotics annually to evaluate crown width, height, stem diameter, stem number and stem volume index. Complete plant harvesting of exotic trees at 2.5, 4.5 and 6.5 years evaluated agroforestry production. Leaves from all four species and pods of exotic species were analysed for chemical composition. Two groups of eight lambs were balanced for mass at selection for an on-farm feeding trial. Browse from exotic trees, comprising a 2:1 ratio of pods to leaves, was fed at 30% as supplement to hay to one group whose mean mass was contrasted with that of the control group fed sorghum bran at 30%.

A. galpinii was a promising species, adaptable to planting away from its origin. Its crown width ranged from 5.86 m in high density plots to 6.08 m at low density and was significantly different among stands ($p = 0.0406$) at 6.5 years. Diameter at breast height (dbh) was significantly different among stands aged 6.5 years ($p = 0.0003$) and ranged between 10.38 cm at high density to 12.48 cm in low density plots, demonstrating a capacity to provide both shade and poles on-farm. At 4.5 years, *F. albida* attained a mean height of 4.5 m and 4.5 cm in dbh but suffered 67% mortality during a severe drought.

Annual fodder production of 0.647 and 0.996 metric tonnes ha^{-1} for leaves and pods of *L. diversifolia* and 1.237 and 1.431 for *L. leucocephala* was recorded in years of average rainfall. Yields of 0.3 and 0.59 metric tonnes ha^{-1} were recorded for both species in the driest year. Equally good agroforestry production was obtained from both low and high density stands suggesting that low density plantings, which foster higher plant survival and reduce disease incidence, are best suited to the semi-arid conditions of Botswana.

The crude protein of leaves ranged between 16.26 (*L. diversifolia*) and 25.25% (*F. albida*). They were highly digestible with more than twice the calcium content livestock require. Crude protein and digestibility measures were significantly different among leaves and varied significantly at different spacings ($p<0.0001$). Pods of the exotic species contained significantly more protein than the leaves ($p<0.0001$).

Lambs supplemented with browse gained 102.33 g per animal per day while the control group gained 83.95 g. There were significant differences between groups during growth ($p<0.05$).

Growing of *A. galpinii,* complemented with *L. diversifolia* and *L. leucocephala,* can supply short and long term feed, and greatly enhance livestock production while diversifying farm feed sources.

OPSOMMING

Volhoubare produksie van vee in semi-ariede Botswana kan verbeter word deur aanplanting van bome op plase om noodsaaklike proteïne en skaduwee te verskaf. Boomaanplanting kan aangemoedig word indien die groei, produktiwiteit en voedingswaarde van bome en hulle bydrae tot die massa toename van vee bekend is. ‘n Studie by Malotwana het twee inheemse boomsoorte, *Acacia galpinii* en *Faidherbia albida* en twee uitheemse boomsoorte, *Leucaena diversifolia* en *L. leucocephala*, by drie spasiërings in ‘n gelykkansige blokontwerp met vyf herhalings ondersoek. Die drie spasiërings het 400, 317 en 241 bome per hektaar verteenwoordig. Die studie is oor ‘n tydperk van 6.5 jaar uitgevoer. Inheemse bome is elke twee jaar en uitheemse bome jaarliks gemeet om kroonwydte, hoogte, stamdeursnit, aantal lote en stam volume indeks te bepaal. Algehele inoesting op 2.5, 4.5 and 6.5 jaar het agro-bosbou produksie bepaal. Blare van al vier boomsoorte en peule van die twee uitheemse soorte is tydens die finale inoesting ontleed vir chemiese samestelling. Twee groepe van agt lammers is volgens massa geselekteer om gebalanseerd te wees by die aanvang van ‘n voedingseksperiment. Veevoer van uitheemse boomsoorte bestaande uit ‘n verhouding van 2:1 peule tot blare is as 30% aanvullend tot hooi aan een groep gevoer en die ander groep is 30% sorghum-semels aanvullend tot hooi gevoer. Die gemiddelde massa van die groepe is aan die einde van die eksperiment vergelyk

A. galpinii was ‘n belowende spesie wat aanpasbaar was vir aanplanting buite sy natuurlike habitat. Op ‘n ouderdom van 6.5 jaar het kroonwydte beduidend ($p = 0.0406$) varieer van 5.86 m in digte persele tot 6.08 m in die minste dig persele en deursnit op borshoogte (dbh) het beduidend ($p = 0.0003$) van 10.38 cm in hoë digtheid tot 12.48 cm in lae digtheid persele verskil, wat ‘n aanduiding is dat dit geskik is vir aanplanting vir pale en skaduwee. *F. albida* het op 4.5 jaar ‘n gemiddelde hoogte van 4.5 m en dbh van 4.5 cm bereik maar mortaliteit was 67%.

Jaarlikse voerproduksie van 0.647 and 0.996 metrieke ton ha^{-1} vir blare en peule van *L. diversifolia* en 1.237 en 1.431 vir *L. leucocephala* is verkry in jare van gemiddelde reënval. Opbrengste van 0.3 en 0.59 metrieke ton ha^{-1} van blare en peule van beide boomsoorte is in die droogste jaar geoes. Ewe goeie agrobosbou produksie is van beide hoë en lae plantdigthede verkry. Dus word lae plantdigthede, wat ‘n beter plantoorlewing en minder aan peste blootgestel is, vir die semi-ariede toestande van Botswana aanbeveel.

Die ru-proteïne van die blare het gewissel tussen 16.26 (*L. diversifolia*) en 25.25% (*F. albida).* Dit was hoogs verteerbaar met meer as twee maal die kalsium-inhoud wat vee benodig. Ru-proteïne en verteerbaarheids-maatstawwe van blare het beduidend tussen soorte en spasiërings verskil ($p<0.0001$). Peule van uitheemse soorte het beduidend meer proteïne as die blare bevat ($p<0.0001$).

Lammers wat ‘n aanvulling van blare en peule gevoer is, se massa het met gemiddeld 102.33 g per dier per dag toegeneem, terwyl die kontrole groep met gemiddeld 83.95 g toegeneem het. Daar was beduidende verskille tussen groepe ($p<0.05$).

Die kweek van *A. galpinii*, asook *L. diversifolia* en *L. leucocephala*, kan voeding op kort en lang termyn verskaf en vee se produksie aansienlik verhoog, terwyl voedingstofbronne op die plaas diversifiseer sal word.

DEDICATION

I dedicate this dissertation to my mother-in-law, Mary Kathleen Walker, a teacher who believed in self-education. My regret is she died before seeing the efforts of her grand-children, Alister and Alison, in their motivated efforts of self-education and ventures in non-traditional family fields of Squash and Music.

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Very often during the writing, the spirit was willing and the flesh was weak but please God allow me to thank myself for the courage to seek to present a case for trees on-farm.

LIST OF ABBREVIATIONS

INTERNATIONAL

ICRAF	International Council for Research in Agroforestry
ILCA	International Livestock Centre for Africa
FAO	Food and Agricultural Organisation
AOAC	Association of Official Analytical Chemists

BOTSWANA

CSO	Central Statistics Office
DAR	Department of Agricultural Research
FAB	Forestry Association of Botswana
GoB	Government of Botswana
SLOCA	Small Livestock Owners in Communal Areas
MoA	Ministry of Agriculture
NAMPAADD	National Master Plan for Arable Agriculture and Dairy Development
NDP	National Development Plan

TECHNICAL

ADF	Acid detergent fibre
NDF	Neutral detergent fibre
ADG	Average daily gain
ADL	Acid detergent lignin
CP	Crude protein
Cw	Crown width
Dbh	Diameter at breast height
DM	Dry matter
IVDMD	In vitro dry matter digestibility
OM	Organic matter

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1.0 INTRODUCTION

1.1 THE IMPORTANCE OF AGRICULTURE IN BOTSWANA

1.1.1 Socio-economic Importance of Agriculture

"Agriculture is the main source of livelihood for the majority of Botswana's population" (Khama, 1979). Despite some industrial development since Independence, agriculture remains the main sector in which Batswana invest and to which they retire (Chiepe, 1994 personal communications). In spite of the importance of this sector, its development has not kept pace with the social and economic interest that it plays in the economy. At the time of Independence in 1966, agriculture contributed 40% to the Gross National Product. According to the Ministry of Agriculture Policy Review of 1990, this figure declined to 4% (GoB, 1991) and, though fluctuating considerably from year to year, continues to decline (MoA-NAMPAADD, 2002). Meat and milk are the main sources of protein and income in the rural economy.

1.1.2 Importance of Small Stock and Ruminants

Small livestock, sheep and goats, which are more readily available to poorer households than cattle, constitute a major source of protein and are particularly important. The support of this sector through various programmes, such as Services to Small Livestock Owners in Communal Areas (SLOCA) and Financial Assistance Programme (FAP), has led to a considerable increase in their population. Between 1979 and 2001 small livestock numbers increased from half a million to over two million (Department of Agricultural Research veterinary count for National Development Plan 9, GoB 1991; GoB, 1997; GoB, 2002). As with beef production, small stock productivity is limited by feed supply. Forty years after Independence, Botswana continues to rely on the import of livestock feed from neighbouring Republic of South Africa and Zimbabwe (Fig 1.1). Conservatively estimated data show that between 1990 and 1995 imports of animal feed increased from 8.5 to 35 million metric tonnes and between 1996 and 2000 increased from 30 to 50 million metric tonnes (CSO, 2002). As a result of high feed costs, resource-poor

households lose livestock in the dry season and during droughts since they cannot afford to purchase supplementary feed.

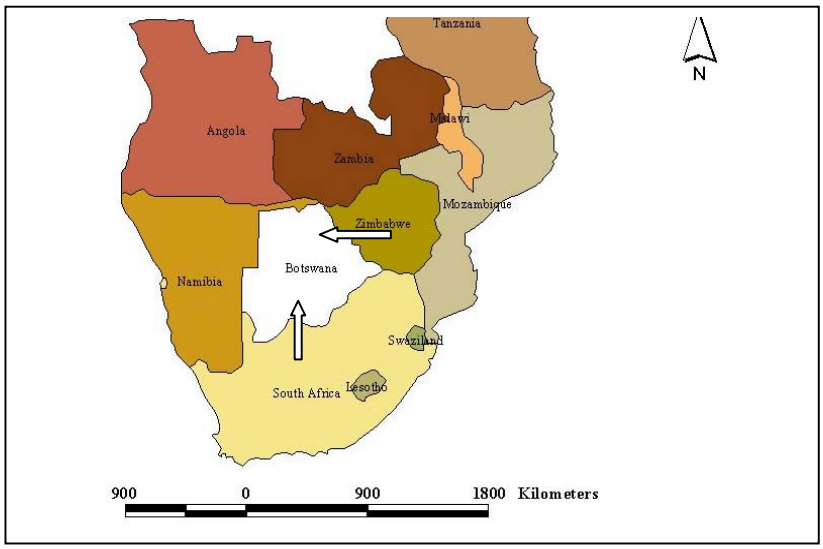


Fig. 1.1 Map showing sources of livestock feed imported into Botswana

1.2 POTENTIAL ROLE OF TREES IN MEETING FEED NEEDS

1.2.1 Socio-economic Importance of Trees

Studies conducted in Botswana (Otsyina and Walker, 1990; Walker, 1992) showed that Batswana believe that trees play a very important role in sustaining livestock throughout the dry season. Appreciation of the role of trees is also found in other African countries such as Tanzania and Kenya (Barrow, 1988). Batswana identify a wide range of indigenous trees that are traditionally exploited through relocation of livestock in years of grazing shortage. Among the many tree species recorded by Otsyina and Walker (1990) are numerous *Acacia* spp., *Combretum* spp. and *Boscia albitrunca*. Such a wide range of trees from region to region within the country poses a considerable dilemma for farm management that aims to integrate trees in farm production in arid zones where the valuable indigenous tree species have not been researched.

1.2.2 Scientific Recognition

Scientific recognition of the role of trees in livestock production in Africa dates back more than three decades with the work of the International Livestock Centre for Africa (ILCA) and the International Council for Research in Agroforestry (ICRAF) founded in 1975. In Botswana individual researchers have documented the importance of tree browse for livestock, (Aganga *et al*., 1999; Barrow, 1988; Scarpe, 1986). Where indigenous trees are concerned, however, most studies have been either of a sociological nature or have involved laboratory analysis for nutrients and limiting factors to tree use such as tannin content. While there is common concern as to the potentially deleterious effects of tannin, it remains true that Botswana's livestock largely depend on tree browse for much of the year and therefore the most suitable species are worth identifying for farm use. Little research has been conducted to evaluate tree establishment, subsequent growth and production of edible products, and their nutritional contribution to livestock production in Botswana.

1.3 MOTIVATION

1.3.1 General

In semi-arid Botswana unreliable rainfall and associated land degradation limit livestock production because of inadequate protein supply in the dry season. Compounding the problem is the expansion of cropland into non-resilient grazing areas associated with increasing human population. Returning trees to cropland to reduce erosion and to maintain land productivity, while ensuring a supply of feed for livestock, is of paramount importance. Silvopastoral promotion, by integrating adapted indigenous trees which provide shade with fast growing exotic trees, can provide both protein feed for livestock and fuelwood as a by-product.

Relevant information on tree species to serve these purposes and to facilitate tree growing by farmers is lacking. Successful promotion of tree planting for sustainable land use and forage production is dependent upon the identification of suitable tree species and the availability of

information regarding their establishment, productivity and nutritional contribution to livestock production.

Acacia galpinii and *Faidherbia albida*, which are indigenous to Botswana, could be good species to ensure sustainable use of land through the provision of shade and an increase in feed production in the form of browse and pods. *Leucaena diversifolia* and *Leucaena leucocephala* are planted and managed in climates similar to that of Botswana. As fast growing exotic species they could be used to ensure economic production is achieved within a shorter period of time than indigenous trees where pods, which are the main feed, might need as long as eight to fifteen years to make a contribution to protein feed on the farm.

1.3.2 The Objectives of the Study

The global objective of this study was to establish a silvopastoral on-farm research trial in order to investigate the potential contribution of trees to livestock production. The specific objectives were threefold:

i. To evaluate, on-farm, the growth and production of four tree species planted at three spacings.
ii. To determine the nutritional value of leaves and pods of these trees as feed for ruminants.
iii. To quantify the effect of feeding the tree leaves and pods on growth performance of dorper lambs.

1.3.3 Background to the Study

1.3.3.1 General

This study was a continuation of the work of Otsyina and Walker (1990) and Walker (1992). Otsyina and Walker (1990) conducted an agroforestry development social study for the Government of Botswana in 1990, to ascertain people's knowledge, perception and appreciation of the importance of trees in household production. The survey covered the whole of Botswana

(Fig. 1.2) using a structured questionnaire. They observed that in all five main ecozones, delineated by rainfall, between seventy and eighty percent of the respondents indicated that trees were important in household production. More than twenty indigenous trees and fifteen shrubs were frequently reported to be important as browse. In general, people were interested in tree planting for fodder but were less willing to plant them in their fields because of their potential to attract birds in a country which predominantly grows sorghum. However, more than forty percent of respondents were keen to plant fodder trees as windbreaks.

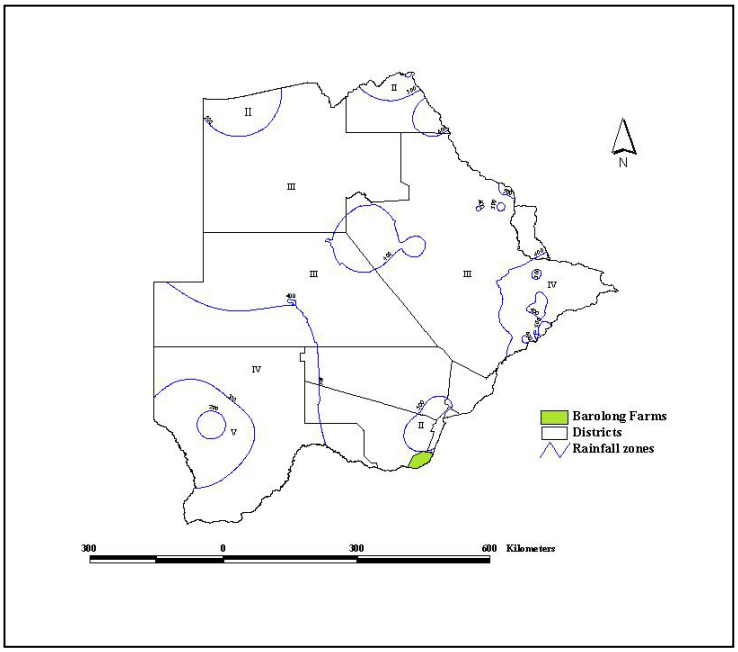


Fig. 1.2 Areas covered by agroforestry development study of Otsyina and Walker (1990)

1.3.3.2 Tree Planting on Farm Land

Walker (1992) extended the scope of the study, focusing on the potential role of tree planting on cropland in the Barolong Farms (Fig. 1.2), a sub-district with a high population and limited land. In the Barolong study, she observed that 65% of farmers were willing to plant trees on farms as windbreaks both for field boundaries and at intervals within them. Of the interviewed farmers, 38% were willing to plant trees within their fields as a means of controlling erosion. Forty percent of farmers interviewed in Barolong were interested in setting aside land within existing landholdings for fodder production, due to the shortage of communal land for grazing and also

because of the high cost of feed which is purchased mostly from South Africa (Fig. 1.1). The studies of Otsyina and Walker (1990) and Walker (1992) identified a wide range of indigenous trees hitherto unresearched for utilisation and nutritional content. These included *Acacia* spp. (*F. albida* included here), *Combretum* spp., *Colophospermum mopane, Lonchocarpus* spp., *Boscia albitrunca, Terminalia* spp. and, among shrubs, *Grewia* spp. The indigenous tree species selected for this study, *F. albida* and *A. galpinii*, were those most frequently cited as having a wide range of uses, being especially important as fodder in the districts where they existed, but not necessarily widely distributed in the country. Of significance is the fact that they were the two fastest growing species in the FAB's Around-the-Home Tree Planting Project initiated in 1989. They therefore seemed to present a higher potential for successful growing on the farm compared to other species, even though they had not been used in high density planting situations. The exotic trees were selected on the basis of literature review findings in other countries of similar climate. They were also preferred by farmers in Barolong, after they had been shown video films of agroforestry projects conducted by ILCA and ICRAF, during the Rapid Rural Appraisal workshop which was part of the Barolong District study (Walker, 1992).

1.4 SELECTED TREE SPECIES

1.4.1 General

The four tree species selected for the study included two indigenous trees, *A. galpinii* (Mokala) and *F. albida* (Mokosho). The role of the indigenous trees was to provide browse in the medium term. In the long term it was to control erosion and provide fodder through the use of pods in the silvopastoral management of the farm. The fast-producing exotic species in the trial were *L. diversifolia* and *L. leucocephala*. The role of these exotics was to provide fodder in the form of leaves and pods on a cut-and-carry basis and to establish whether these can meet the short-term needs of the farm and reduce the purchase of supplementary feed products in the dry season.

1.4.2 *A. galpinii*: Monkey Thorn (Mokala)

A. galpinii belongs to the family Leguminosae, subfamily Mimosaceae (van Wyk and van Wyk, 1999). It is a multipurpose tree, good for fuelwood, construction and for making furniture, even though it is difficult to work (Coates Palgrave, 1983; Motoma, 1998; Tietema *et al*., 1992,). It is frost and termite tolerant and grows well under cultivation, preferring deep, well-drained soils (Poynton, 1984; Timberlake, 1980). It is browseable and its profuse production of leaves makes it an important browse tree. Its pods are edible while its flowers are attractive to bees (Timberlake, 1980). Goats, in particular, browse the species and are commonly found along river banks in Botswana feeding on fallen pods (personal observations; Timberlake, 1980). *A. galpinii* is a fast growing, decorative tree, (Coates Palgrave, 1983; Motoma, 1998; Poynton, 1984) in avenues and road sites, with slender, creamy-yellow spikes and with red to purple calyxes and petals. The pods are purplish-brown and can be up to 28 cm in length and 3.5 cm in width. They are straight, slightly thick and ripen in February-March (Coates Palgrave, 1983) in much of Southern Africa. In Botswana Tietema *et al*. (1992) reported that the seeds ripen in both February and September. The seeds germinate easily and the seedlings are readily established and grow rapidly. The tree grows to 25 m in height, occurring in open wooded grassland and pans. It produces straight stems, often more than one per tree. These are a useful source of straight, good quality poles in Botswana conditions.

1.4.3 *F. albida* : Apple-ring Thorn (Mokosho)

F. albida (Del.) A. Chev. is a unique member of the Acacieae tribe of Mimosaceae (van Wyk and van Wyk, 1999; Wood, 1992). It is a species much written about because of its botanical and phytochemical features which have justified its classification as a separate genus from *Acacia*. It is its bizarre phenological development of losing leaves during the cropping season, thereby providing green manure to the associated crops, which has aroused much interest regarding its potential role in agroforestry (Fagg, 1992; Wood, 1989, 1992). By producing leaves and pods in winter it provides valuable fodder for livestock in the dry season. *F. albida* is one of the largest trees in Southern Africa, growing to a height of 30 m, (Coates Palgrave, 1983; Gutteridge, 1994) with spreading branches and a rounded crown. It is widely distributed in

Africa, suggesting broad patterns of genetic variation (Fagg, 1992). Its sociocultural and economic functions are extensively written about as it is an important source of fodder on farms in arid zones (Timberlake, 1988). It is distributed widely and described by Bonkoungou (1992) as the most favoured tree in Africa's Sudano-Sahelian agrisilvopastoral production. It grows in alluvial soils, along river banks, and in marshy areas (Khonga, personal communications, 2002; Tietema *et al*., 1992). Wood (1992) notes that it is also naturally growing in sites with deep, sandy soils and with mean annual rainfall totals varying considerably from as low as 300 mm to 1000 mm. In Botswana it is restricted to riverine woodland along the Limpopo and Molopo rivers and in the Okavango Delta (Tietema *et al*., 1992; Timberlake, 1980; Wood, 1989). Wood (1989) noted the existence of two races of the species in Botswana and variation of seed to be typical of the river-sourced germplasm. Its bark is greyish-white, and leaves are compound and bipinnate with leaflets borne along the pinnae (Coates Palgrave, 1983; van Wyk and van Wyk, 1999).

1.4.4 *L. diversifolia*

L. diversifolia is one of the three *Leucaena* spp., *L. diversifolia*, *L pallid* and *L. trichandra*, currently considered high yielding yet resistant to the aphid *Heteropsylla cubana* attacking the high yielding *L. leucocephala* (Bray, 1994; Jones, 1998). It has been considered, along with the other two, for interspecific heterosis to improve the yields of *L. leucocephala* whose production in the 1990s was drastically affected by the aphid, and for acid and frost tolerant hybrids (Austin *et al*., 1998; Wandera and Njarui, 1998). The species originates at high altitude in southern Mexico and Guatemala. It is considered to be more tolerant of frost than *L. leucocephala* because of this high altitude origin (Bray *et al*., 1997). It is not as high yielding as *L. leucocephala* (Bray *et al*., 1997). It has been included in more trials than most of the lesser researched *Leucaena* spp., but such research has largely focused on wood yield (Bray, 1994). It occurs as a diploid or tetraploid and has the advantage of being less weedy than the higher yielding *L. leucocephala* species, in addition to being lower in mimosine toxicity (Bray, 1994).

1.4.5 *L. leucocephala*

L. leucocephala is a member of Leguminoseae family, subfamily Mimosoideae, and is the most widely grown leguminous tree in the tropics (Bray, 1994). Although widely planted, it only occurs naturally in Central America and the Yucatan Peninsula of Mexico (Shelton and Brewbaker, 1994). Sixteen species of the genus *Leucaena* are recognised according to Brewbaker's simplistic classification which includes *L. diversifolia and L. leucocephala*. However, Hughes (1998) has identified and named 22 species, six subspecies and two hybrids, an increase of five species since the Bongor, Indonesia, workshop of 1994. Of the four tree species selected for this farm study *L. leucocephala* is the most researched. It is not tolerant of waterlogged or acidic soil sites, with a suggested lower pH limit of 4.8 (Bray, 1994; Mullen *et al*., 1998; Ty, 1998), and one of its potential hazards is soil acidification (Hughes and Jones, 1998).

It is expected to perform best at altitudes lower than 1 500 m, with a mean annual rainfall of 850 mm or higher, though it can survive and be productive even where the mean annual rainfall is as low as 300 mm (Wood, 1992). It is reportedly susceptible to frost, even though it regenerates after such frost damage (Karachi and Lefofe, 1997; Mullen *et al*., 1998). The species produces edible pods and leaves but in most research it has been grown in alley cropping to provide green manure and to limit soil erosion on steeply sloping farmland (Gutteridge, 1998; Mugwe *et al*., 1998; Phien, 1998). In most recent research studies species production has been directed at evaluating its performance under infestation by the psyllid aphid (*Heteropsylla cubana*). Such investigations include control by cross breeding with *L. diversifolia, L. pallid* and *L. trichandra* to improve resistance in the highly productive *L. leucocephala*.

1.5 LOCATION OF THE STUDY AREA

1.5.1 General

Malotwana silvopastoral farm is located in the Kgatleng District of Botswana. It is one of the oldest villages in the country and is typical of the eastern part of Botswana in climate and traditional farming practices.

1.5.2 Climate of Eastern Botswana

The eastern part of Botswana (defined as the area of the country east of a line liking the following three coordinates: 25° 50′ S, 25° 06′ E; 22° 03′ S, 22° 05′ E; 17° 48′ S, 24° 58′ E) has an altitude which varies little from the mean of approximately 1000 msl, but the range of altitude is from 1489 msl at Otse Hill to 520 m in the northern Tuli Block at the confluence of the Limpopo and Shashe Rivers. It displays the characteristics of a semi-arid, subtropical climate with moderate continental influences. Diurnal temperature ranges tend to be large, reflecting the relatively high altitude, the distance from the sea and the high transparency of the atmosphere to solar and terrestrial radiation. Although temperatures in the middle of the day may be oppressive, it is only during periods of abundant cloud cover and high absolute humidity that nights remain uncomfortably hot.

The contrasting seasonal distribution of pressure and winds is responsible for the distinctive rainfall regime, with almost all precipitation occurring in the summer half of the year between October and April. Anticyclonic conditions prevail during the winter months bringing clear skies and high radiation receipts (despite the relatively short day length) over extended periods. Such conditions are responsible for the low minimum temperatures at this time of the year. Winds tend to be light and variable. This pattern of settled winter weather is occasionally broken by the passage of weak cold fronts associated with temperate depressions moving to the south. These bring cloud and, in some cases, limited amounts of rainfall – referred to as “kgogola moko” in Setswana “the rain that washes away the chaff”. As such fronts move away

they are followed by very cold polar air with low daily maximum temperatures and severe night frosts.

In summer, conditions are more favourable for rainfall. The high temperatures of the continental interior cause a trough of low pressure to extend from the inter-tropical convergence zone to the north. The prevailing winds are north easterly and relatively humid; they are subject to convergence and surface heating so that they are readily destabilised. Such conditions produce the conventional rainfall which constitutes the bulk of Botswana's precipitation. It comes largely in the form of afternoon and evening thunderstorms when high rainfall intensity can lead to surface run-off and a consequent risk of soil erosion. Although in Malotwana such erosion is minimised by sandy soil with a high infiltration capacity, the nature of the rainfall and its pattern are features of Botswana that could benefit from the introduction of trees on-farm to intercept such intense rainfall. They would also further improve water inflitration, especially at the beginning of the wet season when the land is bare of grass.

The most important feature of Botswana's rainfall is its unreliability with annual totals showing great variation. Even when a single year's rainfall total seems favourable it may include a lengthy drought at a critical stage of the growing season. Such drought episodes are usually associated with the persistence of the Botswana upper high – an anticyclone at an altitude of approximately 3 km above the surface which suppresses thermals and makes precipitation unlikely. It is only when this weather system weakens or disappears temporarily that the conditions for rainfall become favourable. The degree of persistence of this feature throughout the summer largely determines whether the rainfall in any one year is above or below the annual mean. It also explains the lengthy droughts which may occur during the summer of a year in which the annual total is well above the long term mean (Silitshena and Mcleod, 1992).

As in the whole of Botswana, the environmental conditions at Malotwana present a considerable challenge to plants. They must protect themselves against frost, excessively high summer temperatures, large diurnal temperature ranges, strong winds and very rapid rates of evapo-transpiration. Above all, the dry winters, when in some years no rain may be recorded over a

period of six months, and the prevalence of drought conditions in summer demand effective physiological adaptations if plants are to survive the challenging environment. Once established, the advantage of trees over grasses is that the above ground shoots, while susceptible to frost, recover at the start of the summer and intercept water when the rains begin and provide a standing crop to protect the soil. Similarly a few widely spaced trees, once established, can provide a considerable quantity of pods as dry season fodder, as in much of the Sahelian region (Timberlake, 1988).

1.5.3 Soil

According to the Food Agricultural Organisation (FAO), (1985), the soil of Malotwana is classified as Kalahari Sand (KS soils) and is well drained with a low organic matter content. The results of the detailed soil data for the site are summarised in Appendix 3.

1.5.4 Vegetation

The vegetation of Malotwana Village was described by the author using Coates Palgrave (1983), Fielding (1978), Timberlake (1980), Woollard (1984), and van Wyk and van Wyk (1999) to identify trees and the understorey growth. The vegetation is predominantly made up of *Terminalia sericea* (Mogonono) and *Dichrostachys cinerea* (Moselesele), with sparse trees of *Burkea africana* (Monato), *Peltophorum africanum* (Mosetlha), *Ochna pulchra* (Monyenyele) and *Boscia albitrunca* (Motlopi). The under-storey consists of *Grewia flava, G. flavescens, G. bicolar* and *G. retinervis*. The main grass is *Heteropogon contortus* (Seloka).

1.6 SOCIAL ASPECTS

Malotwana Village was established in 1803 (Bophuthadikobo Museum displays, Mochudi) and has a human population of approximately 500. It is a growing village which retains the possibility of pursuing mixed agricultural production on a single site. Such a system should prove more cost effective than the traditional practice of distributing labour and management among the three homesteads of the village, the cattle post and the “lands” where cultivation

occurs. Such a “three site system” is traditional in most of Botswana and had the advantage of separating livestock and crops without the cost of fencing (Silitshena and Mcleod, 1992). In modern times this system foregoes most of the advantages of more integrated farming systems. It has always suffered from adverse social effects whereby families were separated for long periods, with men and boys at the cattle posts, women and girls in the lands, and with old people and young children remaining in the village. Moreover, with a majority of rural households headed by women and most children being in school, the traditional division of labour, upon which the system depended, is rarely sustainable under modern conditions. Indeed, it has long been apparent that it needs to be replaced by a much more integrated system located at a single site if small farmers are to be provided with more than a bare subsistence.

2.0 LITERATURE REVIEW

2.1 DEFINITIONS

2.1.1 Agroforestry

Agroforestry is defined by Franzel and Scherr (2002) as, "A dynamic, ecologically-based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels".

2.1.2 Silvopastoralism

Silvopastoralism is a branch of agroforestry which may be defined as the integration of trees with pasture or as the purposeful planting and/or management of trees for the improvement of livestock (Steppler, 1987; Wood and Burley, 1991). By meeting the protein needs of livestock on-farm it can reduce the purchase of feed, save the nation foreign exchange and, through wood by-products, reduce pressure on natural woodland while controlling erosion on farmland (Franzel and Scherr, 2002). While historically the opportunistic exploitation of forage in the veldt goes a long way back in Africa, the planting and management of trees for this purpose is recent. A considerable number of tree species is known to provide useful forage and potential feed supplements. *F. albida* is the better known of the two indigenous trees, *F. albida* and *A. galpinii*, whereas *L. leucocephala* is the most widely planted exotic in the tropics (Stewart and Dunsdon, 1998).

2.2 *A. galpinii*

2.2.1 General

The importance of *A. galpinii* as a browse species is documented by Timberlake (1980). Studies on germination of the species in the nursery have shown that it is an easy-to-germinate and fast-

growing tree (Tietema *et al.*, 1992; Motoma, 1998). However, at field level the species is little researched.

2.2.2 Survival

The assessment of the performance of a number of species in elimination trials (Fig. 2.1) conducted by the FAB between 1987 and 1991 in different locations showed mixed results for *A. galpinii*, but was generally promising (Kooiman, 1992). Data collected five months after planting in Shoshong recorded a 95% survival which declined to 85% three and a half years after planting. At the Serowe trial the comparable values for survival were 100% and 98% for the respective years. Results of the trial at Pelotshetlha, outside its natural habitat, showed a 43% survival at three and a half years which may be associated with poor drainage of the soil in the area.

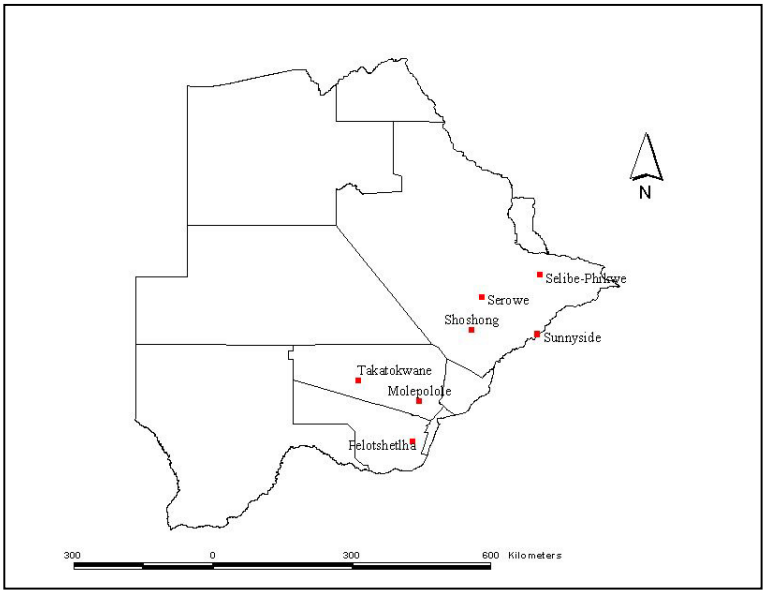


Fig. 2.1 FAB Species elimination trial sites

The mean annual rainfall of Malotwana Village is similar to that of Serowe, Shoshong and Pelotshetlha, rainfall zones of Otsyina and Walker, 1990 (Fig. 1.2). The soils of the three sites are shown in Table 2.1

Table 2.1 Soils of Serowe, Shoshong and Pelotshetlha FAB trial sites (Kooiman, 1992).

Vil. *	Parent Material	Broad soil description	Measured (data from 40-80 cm depth)							
			pH	P(ppm)	CEC	Ca	K	Mg	Na	O.C.
Ser	Basalt	Moderate to deep soil dull dark reddish brown sandy loam	7.4	2.7	13.2	8.4	0.40	1.05	0.86	0.35
Sho	Alluvial derived from Dolerite	Deep 100 cm + brownish black sandy clay to clay	7.5	3.8	27.0	16.9	0.30	4.25	0.42	0.25
Pelo	Granitic gneiss + alluvial	Deep 120 cm + Grey yellowish brown clay	5.5	4.0	16.4	3.7	0.14	0.70	0.29	0.15
			7.5	0.6	7.8	2.0	0.01	0.23	0.00	0.35

*Ser =Serowe Sho = Shoshong Pelo = Pelotshetlha

2.2.3 Height and Diameter Growth

Growth and performance of *A. galpinii* in the field has been little studied. In the two areas (Shoshong latitude 23° 02′ S, longitude 26° 31′ E; altitude 1213 m a.s.l. and Serowe 22° 24′ S, 26° 43′ E; altitude 1214 m a.s.l.) where the species occurs naturally, although seedling establishment was high, growth in height was not impressive, at 55 cm and 95 cm in Shoshong and 46 cm and 130 cm for Serowe at the ages of five months and three and half years respectively (Kooiman, 1992). At three and a half years after planting the maximum height of the tree had only reached the level at which diameter at breast height (dbh) is measured (1.30 m) in Kooiman's evaluation of the trials (1992). In Bawal, India (latitude 28^{o} 6' N, longitude 76^{o} 3' E; altitude 266 m a.s.l), evaluation of an eight year old stand of *Prosopis cinerea* and *A. tortilis*, which like *A. galpinii* are multistemmed (Saini and Yadav, 1989), recorded heights of 8.9 and 7.3 m. Mean tree dbh recorded was 7.1cm for *P. cineria* and 6.01 cm for *A. tortilis*.

2.2.4 Nutritional Composition of *A. galpinii*

Nutritional analysis of *A. galpinii* has been carried out at the Botswana College of Agriculture in Sebele, Gaborone. Chemical analysis of leaves in the study showed crude protein of 15.62 g/100 g of dry matter, while seeds of the species contained 31.22 g/100 g of dry matter (Aganga *et al.*, 1999). The high crude protein content of seeds explains why pods of the tree species, with seed intact, contain more crude protein than the leaves, as seeds, retained in pods, determine the crude

protein of the pods (Nyambati *et al.,* 1996). Leaves of the species were found to have high crude protein at 97.32 g/100 g of dry matter (Aganga *et al.,* 1999). The higher crude protein content of seeds may explain the consumption of pods by goats around river banks in order to supplement their low protein dry season feed. The digestibility measurements of leaves of *A. galpinii* recorded in their study were 22.62, 19.87 and 93.68 g/100 g of dry matter for NDF, ADF and IVDMD respectively (Aganga and Nsinamwa, 1997). Mineral content was found to be 0.63, 0.24 and 0.14 g/100 g of dry matter for calcium, magnesium and phosphorus respectively (Aganga *et al.,* 1999).

2.3 *F. albida*

2.3.1 General

F. albida is the most commonly cited tree in the silvopastoral system of the semi-arid zones of Africa. According to Bonkoungou (1992), economic interest in the species goes back to the early 1950s, although research was not initiated until 1966. Initial research on the species focused on its contribution to improved yields of cereal crops such as millet, maize and wheat, grown in association with the tree in much of the Sudano and Sahelian zones of Ethiopia, Malawi, and Niger (Bonkoungou, 1992; Cisse and Kone, 1992; Edwards, 1982; Poschen, 1986). In the late 1970s and during much of the 1980s interest in the tree shifted to seed collection and the creation of seed banks to build up the genetic resources which would facilitate the establishment of trials (Bonkoungou, 1992; personal participation in collection for Oxford Forestry Institute).

2.3.2 Survival

Considerable variation in the establishment, performance and survival of the species is reported by many of the researchers. In Matopo, Zimbabwe (latitude 20^{o} 23' S, longitude 28^{o} 31' E; altitude 1180 m a.s.l.; a mean annual rainfall of 560 mm), preliminary results of the trial evaluation (Wanyancha *et al*., 1994) in the first year showed that seedlings grown from seed obtained from Southern Africa performed better than those established from seed acquired from

West African genetic material. In south Niamey, Niger (latitude 13^{o} N, longitude 2^{o} E; altitude 216 m a.s.l.; mean annual rainfall 562 mm; soils described as acidic and in an area where the water table was at 20 m), Vandenbeldt (1992) recorded good field performance of seedlings grown from Southern African seed in the first year. However, by the second dry season seedlings grown from Southern African seed had died, while seedlings grown from Sahelian seed achieved 95% survival. Similarly variable results in Ouagadougou, Burkina Faso (latitude 12^{0} 21' N, longitude 1^{0} 31' W; altitude 304 m a.s.l; mean annual rainfall 850 mm; ferruginous soils with clayey-sand texture), were reported. Mortality ranging from 6% to over 50% in 20 progenies grown from seed collected from Congo (Burkina Faso), Mataye (Niger) and Kagnobon (Senegal) was recorded (Billand, 1992). At Tumbi in the Tabora region of Tanzania (latitude 5^{o} 03' S, longitude 32^{o} 41' E; altitude 1190 m a.s.l.; annual rainfall ranging from 790 to 1080 mm), much better survival rates of 87 % and 86% six and 30 months after planting respectively are reported (Karachi *et al.,* 1997).

2.3.3 Height

Evaluation of trees in the trial at Matopo three years after planting showed mean heights ranging between 0.58 and 2.31 m. Great variations in height of trees grown from seeds from different countries, as well as from different provenances from within the same country, were recorded. Of the four provenances from Zimbabwe, three were in the best performing top ten among the 31 provenances tested, suggesting a case for national seed investigation (Wanyancha *et al*., 1994). However, the best performing Niger provenance in the whole trial was three times better than the worst Niger provenance, perhaps suggesting big variation among provenances within Niger and hence material sourced for the trial. Wanyancha *et al.* (1994) reported mean heights of 0.58 to 2.31 m three years after planting at Matopo, Zimbabwe, in different provenances planted in the trial. Poor growth was ascribed to shallow clay soils, in contrast to the deep alluvial soils in areas where the species is commonly found (Wanyancha *et al*., 1994).

In the study of *F. albida* carried out at Ouagadougou, growth in height varied between progeny, from 1.14 ± 0.05 m to 1.93 ± 0.08 m, three and a half years after planting (Billand, 1992). The results of growth studies showed variation with soil depth (Billand, 1992). In south Niamey,

Niger, surviving trees varied widely in height, 0.78 to 2.25 m with a mean of 1.45 ± 0.55 m, 2.5 years from planting (Vandenbeldt, 1992). In Niamey soils were described as poor and acidic in a site with the water table at 20 m (Vandenbeldt, 1992). Growth varied in relation to both the micro-relief of the field and proximity to eroded termite mounds (Vandenbeldt, 1992), with trees in higher terrain and those near termite mounds attaining good heights. The growth reported for the study in Tumbi, Tanzania, was promising both in survival and in height, with means of 0.7, 1.6 and 2.2 m, 6, 14 and 30 months after planting respectively (Karachi *et al*., 1997).

A detailed assessment of trees grown at Mafiga, Morogoro, Tanzania, (latitude 6^{o} 50' S, longitude 37^{o} 38' E; altitude 520 m a.s.l.; annual rainfall ranging between 600 and 1000 mm) was carried out (Okorio and Maghembe, 1994). Performance of *F. albida* grown at three spacings of 4 x 4, 5 x 5 and 6 x 6 m, both as monoculture and in stands integrated with food crops, was reported over six years by Okorio and Maghembe (1994). They showed that throughout the study height was neither influenced by density nor by the presence of the understorey crop, and that site factors were more important influencing conditions. The mean height achieved in eight years was 8.4 m (Okorio and Maghembe, 1994).

In Mouda, Cameroon, with a mean annual rainfall of 850 mm, equally promising results to those of Okorio and Maghembe (1994) are reported. The mean height recorded at Mouda was 4 m after five years of growth. There were, however, considerable variations between blocks which were positively correlated with soil depth (Harmand and Njiti, 1992). They ascribed the height variations to soil heterogeneity. A deep water table was also suggested as a possible cause of poor growth because trees could not benefit from underground water (Harmand and Njiti, 1992).

2.3.4 Diameter at Breast Height

Limited data currently exist on diameter at breast height (dbh) of planted *F. albida*. Basal diameter measurements reported at Tumbi, Tabora, Tanzania, were 3.0 and 5.4 cm at 14 and 30 months after planting (Karachi *et al.*, 1997). Dbh measurements for the study conducted at Mafiga, Morogoro, showed significant differences among densities of planted *F. albida* stands (Okorio and Maghembe, 1994). Mean tree dbh was not affected by intercropping, but there were

statistically significant differences among trees at different spacings. A mean tree diameter at breast height of 10.7 cm was recorded. Maize and bean yields were not affected by intercropping and in all plots mean height was not affected by density (Okorio and Maghembe, 1994). Trees in the 4 x 4 m spacing had significantly smaller diameters than those in low density 6 x 6 m plots. No statistical differences were observed between trees spaced at 5 x 5 m and those at 6 x 6 m, even at eight years (Okorio and Maghembe, 1994), possibly because spacing was not sufficiently different between the 5 x 5 and 6x 6 m plots. The study suggested that planting density should be determined by end-use, with trees planted for intercropping being at low density, while for wood production closer spacing facilitates high wood yields (Okorio and Maghembe, 1994). In their study of *L. leucocephala* intercropped with maize, Maghembe *et al*. (1986) also found basal diameter was significantly greater in low density plots.

2.3.5 Pod Production of *F. albida*

Although leaves, small stems and bark contribute to the fodder value of indigenous trees, pods are by far the most important and documented in social studies (Barrow, 1988; Bonkoungou, 1992; Timberlake, 1980; Timberlake, 1988). There is, however, a lack of documentation on methods of quantifying pod production of *F. albida* and other indigenous trees (Cisse and Kone, 1992). Both the reported age at which pod production begins and the productivity of *F. albida* are highly variable. Cisse and Kone (1992) noted that pods of the species mature very slowly.

The reported quantities of pods produced by the species are also highly variable (Cisse and Kone, 1992). Jung is reported by Cisse and Kone (1992) to have recorded fruit production of 125 kg from a tree of crown surface 230 m^2 in Bambey, Senegal, and Wickens to have reported harvesting 135 kg from a tree in Sudan (Cisse and Kone, 1992; Timberlake, 1980). It is therefore safe to conclude that both production and the age of first production of pods of *F. albida* are highly variable (Cisse and Kone, 1992) and the results of this study may pave the way for similar research in Botswana and make a contribution to knowledge of the species.

2.3.6 Nutritional Composition of *F. albida*

Nutritional analysis of agroforestry products from the species using the Van Soest method (Reed *et al.*, 1992, Wiegand *et al.*, 1996), showed that leaves of *F. albida* contained 20.1 g/100 g of dry matter crude protein, 31.8 g/100 g of dry matter NDF and 10.7 g/100 g of dry matter ADL. These nutritional values of *F. albida* compared well with the values of 25.6, 25.2 and 6 g/100 g of dry matter for *L. leucocephala* respectively in the study conducted by Reed *et al.*, (1992). Their study also showed that rams fed on the leaves of *F. albida* showed similar growth rates to those fed on leaves of *L. leucocephala* (Reed *et al.*, 1992). NDF and ADF analysis of leaves of *F. albida* showed considerable variation in different seasons (Cisse and Kone, 1992). For example, the results of nutritional analysis for December, February and March were 35.5, 39.8 and 30.9 g/100 g of dry matter and 22.1, 22.9 and 19.7 g/100 g of dry matter for NDF and ADF respectively, while ADL values were 7.9, 9.4 and 9.5 g/100 g of dry matter. Analysis conducted by Aganga *et al.* (1999) showed NDF and ADF values of 12.22 and 19.39 g/100 g of dry matter and *in vitro*-digestibility (IVDMD) of 92.73 g/100 g of dry matter. Calcium, magnesium and phosphorus contents reported in their analysis were 0.63, 0.16 and 0.14 g/100 g of dry matter, with a crude protein content of 29.32 g/100 g of dry matter.

2.4 *L. diversifolia* and *L. leucocephala*

2.4.1 General

L. leucocephala is the best known and most comprehensively studied multipurpose tree of the tropics and subtropical region (Tolera *et al.*, 1998; Stewart and Dunsdon, 1998). Recognition of the value of *Leucaena* genus goes back 400 years when the Spanish conquistadors in South America cut its forage for livestock feed and harvested its seed for planting in the Philippines (Shelton and Brewbaker, 1994). The productivity of *L. leucocephala* is reported to be highest in non-acidic soils, and with a mean annual rainfall ranging between 650 to 1500 mm. Temperature sets a limit to production with highest values with mean maximum temperatures of 25 - 30^{o}C. These are achieved at altitudes above 1000 m within 10^{o} of the Equator, and above 500 m at the latitudes within 10-25^{o} of the Equator (Shelton and Brewbaker, 1994). The growth

of *L. leucocephala* is reported to increase linearly with increases in mean annual rainfall between 800 and 1500 mm (Shelton and Brewbaker, 1994). Growth of 4.5 m in height in a two year stand in Waipea, Hawaii, at an elevation of 850 m and with a mean annual temperature of 17^{o}C was recorded (Shelton and Brewbaker, 1994). Estimated yields ranged from 3 - 10 tonnes ha^{-1} dry matter and, in poorer conditions, 1.5 - 10 tonnes ha^{-1}. Studies conducted over four years at nine sites of contrasted soil type and acidity in Vietnam showed the influence of soil on the productivity of the species (Ty, 1998). The primary conclusion drawn from the results (Ty, 1998) was that *L. leucocephala* will perform well in soils of pH 4.8 and higher, but will do poorly with a pH below this limit, possibly because of the influence of pH on the uptake of some nutrients needed for plant growth. Similarly, highly acidic conditions are likely to inhibit the activity of micro-organisms. *L. diversifolia* grows in deep, free draining soils of mildly acid reaction with a pH value between 5.5 and 6.5 (Anon, 2007). It grows best with an annual rainfall of between 700 – 2500 mm (Bray and Sorensson, 1992). It has potential to colonise bare ground from seed but is unlikely to spread under grazing conditions and there are no records of weediness. Most accessions are tolerant of regular cutting in trials conducted in Hawaii, Florida, Australia and Southern Asia (Anon, 2007).

2.4.2 Survival

Survival and growth rate measurements of *Leucaena* spp. are rarely reported in studies of the genus in recent publications and current research has focused on productivity, frost resistance and tolerance to the aphid pest (*Heteropsylla cubana*). Generally survival in *Leucaena* is more than 80% in most sites, hence, perhaps, the concentration on productivity, as survival is generally high even when production is low. At Tumbi in the Tabora region of Tanzania (latitude 5^{o} 03' S, longitude 32^{o} 41' E; altitude 1190 m a.s.l.; with an annual rainfall ranging between 790 to 1080 mm over the period of the study) Karachi *et al.* (1997) evaluated 15 leguminous trees and reported 100% survival in *L. leucocephala* over the first six months and 92% at age 2.5 years. In Molepolole and Selebi-Phikwe, Botswana, a survival rate of 100% in both *L. leucocephala* K8 and K28 was reported in the species elimination trials. Browsing of trees and poor management overshadowed the long term measurement of the species performance (Kooiman, 1992). In Vietnam a study of the performance of *L. leucocephala* over

four years showed varying yields in eight sites of wide ranging soil fertility. The results of the study showed survival rates of 85 to 90% in the first year in the most suitable soils, with heights of 6.6 to 7.1 m at the end of the second year of growth. By contrast, on unsuitable sites mean heights ranged from 2.4 to 2.5 m (Ty, 1998).

2.4.3 Height and Diameter

At Tumbi in the Tabora region of Tanzania, mean heights of 1.2, 3.9 and 4.9 m for *L. leucocephala* were recorded 6, 14 and 30 months from planting. Root collar diameters were 6.4 and 7.7 cm for *L. leucocephala* at 14 and 30 months from planting respectively (Karachi *et al*., 1997). In Botswana, evaluation of the performance of 36 accessions of *Leucaena* was conducted at Morale Ranch in Mahalapye (Karachi and Lefofe, 1997), with a mean annual rainfall of 450 mm. Mean tree height ranged from 0.65 to 1.86 m among accessions ten months after planting. For *L. leucocephala* K636 height ranged between 1.27 and 1.42 m, with comparable values for *L. diversifolia* of 0.99 to 1.47 m ten months after planting (Karachi and Lefofe, 1997). This indicated the considerable potential of both species.

In Hisar, India (latitude 29^{o} 10' N, longitude 75^{o} 46' E; altitude 215 m a.s.l. and an annual rainfall of between 350 to 400 mm), Bisht and Toky (1989) reported heights of 2.74 ± 0.13 m and 4.31± 0.11 m respectively in regularly watered *L. leucocephala* and *Sesbania sesban* plants aged 12 months.

In Mafiga, Morogoro, Tanzania (latitude 6^{o} 50' S, longitude 37^{o} 40' E; altitude 500 m a.s.l; mean annual rainfall of 860 mm and a soil pH of 6.5), an evaluation of a four year old stand of *L. leucocephala* recorded mean subplot heights ranging from 7.0 to 7.8 m (Maghembe *et al.*, 1986). In a trial investigating the effects of spacing at 3 x 3, 4 x 4 and 5 x 5 m, variations in mean height, diameter at base and biomass yield were found to be marked. Mean tree height and mean stem diameter were significantly greater in low density spacings, but total air dried biomass was significantly greater in high density plots because of greater number of stems per hectare. Mean stem diameter recorded in the experiment was 10.8 cm in high density plots, 12.9 cm in medium and 14.9 cm in low density plots (Maghembe *et al.,* 1986), showing a significant difference

among the three spacings. The differences in mean tree heights were ascribed to within-plot competition among plants as the soil was uniform throughout the site (Maghembe *et al.*, 1986).

Preliminary results of a study of 22 *Leucaena* species in Atenas, Costa Rica, Central America, (latitude 9^{o} 58' N, longitude 84^{o} 23' W; altitude 200 m a.s.l.; mean annual rainfall 1600 mm), recorded mean heights of 1.2, 0.9 and 1.2 m 9.8 months from planting for *L. diversifolia*, *L. leucocephala* K8 and K636 respectively (Argel and Perez, 1998). The heights of the two *L. leucocephala* (K8 and K636) and *L. diversifolia* were among the top five of the 22 *Leucaena* species in the trial. Evaluation of a two-year stand of six *Leucaena* species in Dodangolla, Sri Lanka, (mean annual rainfall 1563 mm) showed a mean height of 6 m, with *L. diversifolia* giving the greatest height and diameter at breast height. However, *L. leucocephala* had more numerous shoots/stems than *L. diversifolia* (Wickremasinghe and Gunasena, 1998).

2.4.4 Yields of Agroforestry Products

In the trial at Tumbi, Tabora, Tanzania, with mean annual rainfall of 1080 mm and a soil pH of 4.9, the reported oven-dried leaf mass of *L. leucocephala* varied from 1.7 to 4.6 tonnes per hectare per year (Karachi *et al.*, 1997). In the evaluation of *L. leucocephala* at Mafiga, Morogoro, Tanzania, oven-dried total biomass yield for trees aged four years varied from 22.4 tonnes per hectare in low density stands (5 x 5 m) to 30.5 tonnes per hectare in high density (4 x 4 m). Wide spacing resulted in greater basal diameters whereas biomass yield was highest in the high density plots (Maghembe *et al.*, 1986). In Harvana, India, oven-dried biomass yields of *L. leucocephala* aged one year were 19.7, 29.6 and 6.2 tonnes per hectare for leaves, stems and branches respectively, for trees spaced at 0.25 x 0.25 m and watered regularly (Bisht and Toky, 1989).

In Gowa, South Sulawesi, Indonesia, Ella and Blair (1989) found the leaf yield per hectare of *L. leucocephala* increased with planting density and with a reduced frequency of cutting. Wood mass decreased with decreasing density but increased with less frequent cutting for both *L. leucocephala* and *G. sepium*. Ella and Blair (1989) reported that for *L. leucocephala* survival and yield were not affected by cutting, and yields were better than for *G. sepium*, *C. calothyrsus*,

and *S. grandiflora* at cutting intervals of both 6 and 12 weeks. Leaf yields of twelve week old trees were greater than those of plants harvested twice at six week intervals.

In Ibadan, Nigeria (latitude 7^{o} 30' N, longitude 3^{o} 54' E; altitude 240 m a.s.l.; mean annual rainfall 1530 mm; sandy loam soil of pH 6.2), a longer cutting interval of 4 times a year was shown to produce more leaf dry matter annually than cutting intervals of 5, 6, and 8 times a year, with the lowest yield from the most frequently cut interval. Similarly a wider spacing of 20 000 trees per hectare recorded the lowest yield per hectare compared to stocking densities of 26 000, 40 000 and 80 000 trees per hectare. The results suggested that widely spaced *L. leucocephala* does not take advantage of wide spacing to produce more stems to compensate for the low planting density (Cobbina, 1998).

In Dodangolla, Sri Lanka, (latitude 7^{o} 15' N, longitude 80^{o} 45' E; altitude 367 m a.s.l.; mean annual rainfall 1563 mm), the reported leaf yield was generally positively related to wood production (Wickremasinghe and Gunasena, 1998), but a correlation coefficient was not stated. Regenerating stumps of *L. diversifolia* and *L. leucocephala*, 12 weeks after cutting, recorded heights well over a metre (Wickremasinghe and Gunasena, 1998) with greater branching being exhibited by *L. leucocephala*. Oven-dried leaf yields of *L. diversifolia* provenances varied between 0.1 and 0.5 kg per tree, while the wood yield ranged from 0.5 to 1.9 kg for trees harvested two years after planting. For *L. leucocephala*, oven-dried leaf yield was 0.3 to 0.6 kg per tree and the wood yield averaged 1.7 kg per tree at the age two years (Wickremasinghe and Gunasena, 1998).

In Machakos, Kenya (latitude 1^{o} 30' S, longitude 37^{o} 15' E; altitude 1600 m a.s.l.; mean annual rainfall 717 mm), the performance of *Leucaena* was evaluated over three seasons harvested at 2 and 4 month intervals commencing six months after transplanting (Wandera and Njarui, 1998). Annual oven-dried yields were averaged over the three years of the trial. Values of 38.6, 65.8, 60.0 and 60.8 g per plant were recorded for *L. diversifolia* originating from four seedlots. For *L. leucocephala* K8 and K636, leaf production of 54.5 and 61.4 g per tree respectively was reported. Stem dry matter ranged from 9.1 to 25.7 g per plant for *L. diversifolia* and between 12.1 and 17.6 g per plant for K8 and K636. Hybrids of *L. leucocephala* and *L. diversifolia*

yielded more highly than their parent material in both leaf and stem per plant (Wandera and Njarui, 1998).

Leaf yields reported at Morale Ranch in Botswana were highly variable, with values of 200 g per tree for the highest yielding species ten months after planting. Exceedingly low yields of 0 to 30 g per tree in some accessions were reported by Karachi and Lefofe (1997), suggesting the need to identify species that are more productive for Botswana. Karachi and Lefofe (1997) did not indicate the quantities of water used in their study, although generally trees in Botswana are watered during the establishment period. However, they reported frost and the regeneration of trees in the post-frost season. With almost all rainfall distributed between October and April in Botswana, it is likely that the yields reported by Karachi and Lefofe (1997) were based on seasonal rainfall, as is the case in leaf and pod yields for all other species they have researched.

In Tumbi, Tabora, Tanzania, over three years with rainfall totals of 520, 489 and 732 mm, yields of edible dry matter of 0.6, 11.5 and 4.4 tonnes per hectare were recorded (Karachi, 1998). Performance among the eleven accessions tested differed significantly ($p<0.05$), with *L. diversifolia* coming third after *L. pallid* and a *Leucaena* hybrid. While increased biomass was reported in the second year of the trial, yields were considerably reduced in the third year despite a relatively high rainfall during the season, due to the arrival of the *Leucaena* psyllid (Karachi, 1998).

At Pakchong, Thailand (latitude 14^{o} 38' N, longitude 101^{0} 19' E; altitude 388 m a.s.l.; sandy, clayey-loam soils with pH 6.5), the performance of *Leucaena* was studied over a three year period. Annual rainfall totals for the period were 1032, 1314 and 1546 mm and trees were grown at three spacings of 1, 2 and 4 metres (Tudsri and Kaewkunya, 2002). Reported dry matter yields were 2.32, 1.09 and 0.64 tonnes per hectare in the first year after planting in the respective spacings, and 3.53, 1.58 and 0.81 tonnes per hectare in the second year. In the third year their results showed yields of 2.86, 1.44 and 0.67 tonnes per hectare (Tudsri and Kaewkunya, 2002) despite higher rainfall than in year two. Increased spacing depressed yields of *Leucaena* by 53-76%, but increased the yields of the associated grass crop. However, the results of the study showed that the combination of widely spaced *Leucaena* and grass produced

10% more dry matter than the higher density *Leucaena* combinations (Tudsri and Kaewkunya, 2002). Increasing the spacing from 1 to 4 m depressed the yields per hectare of *Leucaena* but yielded a greater total biomass than the high density stand of *Leucaena*. The results of their study suggested the benefits of high density spacing of *Leucaena* to meet protein-need combinations (Tudsri and Kaewkunya, 2002). It is suggested that a combination of cereal crops and leguminous trees should be afforded major consideration in determining silvopastoral plantings.

2.5 NUTRITIONAL ANALYSIS OF BROWSE FEED

2.5.1 General

The contribution of trees and shrubs to livestock production in semi-arid and arid countries is well recognised. Although most African countries are yet to quantify the degree of dependence of animals on browse, Hawtin (1990) suggests that in Africa browse constitutes 60-70% of the range biomass and accounts for 40% of total feed. With the expansion of cropland into fragile grazing land and the associated degradation of annual plants, the many tree species reported by farmers to play a significant role in livestock production have come to the attention of scientists. However, with this realisation has come a heightened concern over tannin and phenolics found in browse which are considered to be potentially dangerous to animals (Boitumelo, 1999). Fortunately methods developed by the Association of Official Analytical Chemists (AOAC) provide agroforesters with basic tested methods for investigating the digestibility of browse feed products and their mineral and tannin contents. This can facilitate the incorporation of browse in livestock feed and the selection of trees suggested by farmers as being most appropriate, although quantification through livestock feeding trials is needed to support the nutritional results of such analysis (Norton, 1994).

2.5.2 Chemical Composition of Browse

The digestibility, mineral composition and tannin content of browse are well documented (Aganga and Monyatsiwa, 1999; Aregheore, 2002; Bosma and Bicaba, 1997; Felker *et al.*, 1999; Gutteridge, 1994; Karachi, 1998; Nyambati *et al.*, 1996; Rangkuti *et al*., 1989; Stewart and

Dunsdon, 1998; Wiegand *et al.*, 1996). The extent to which each species has been researched depends on the degree of interest in the genus or species, with *L. leucocephala* being the most researched leguminous tree. *F. albida* and *A. galpinii*, like many local species, have been less studied.

The chemical composition of browse has been studied by several researchers and is well documented. Reported crude protein content ranged from 8.6 g/100 g of dry matter in *Euclea schimperi* in Botswana *(*Aganga and Monyatsiwa, 1999) to as high as 31.2 g/100 g of dry matter in *L. leucocephala* K636 in Apia, Samoa (Aregheore, 2002,).

Chemical analysis conducted at the Oxford Forestry Institute showed variations in the crude protein content in the leaves of twenty-two known species and five hybrids of *Leucaena* collected from a single site in Honduras. Such variations were found both between species and within taxa (Stewart and Dunsdon, 1998). Reported crude protein content of *L. leucocephala* ranged from as low as 12.64 g/100 g of dry matter (DM) to as high as 27.6 g/100 g of dry matter (Nyambati *et al.*, 1996; Aregheore, 2002). In Apia, Samoa, crude protein contents of 27.6, 29.3 and 31.8 g/100 g of dry matter in dry, wilted and fresh leaves of planted *L. leucocephala* were reported (Aregheore, 2002).

Investigation into measures of digestibility such as NDF and ADF by researchers showed considerable variation within species, from 27.5 to 46.3 g/100 g of dry matter and 26.2 to 44.2 g/100 of dry matter respectively in the case of *L. leucocephala* (Aganga and Monyatsiwa, 1999; Karachi and Zengo, 1998; Wheeler *et al.*, 1994). Such variations are reported to relate to site factors such as soil nutrition, age of the plant, sampling method and the season of harvest of the material (Aregheore, 2002; Stewart and Dunsdon, 1998). Stewart and Dunsdon (1998) found such variations both within taxa and among species of *Leucaena*, although they suggested that sampling methods and analytical technique may also contribute to the variation.

In studies carried out at Apia, Samoa, the percentage NDF varied between 38.6, 44.4 and 59.3 g/100 g of dry matter in fresh, wilted and dry *Leucaena* leaves respectively (Aregheore, 2002). Organic matter also varied according to whether the material was fresh, wilted or dry, being 95,

94 and 90.5 g/100 g of dry matter. The minerals phosphorus and calcium, as a percentage of dry matter, were consistent, regardless of the freshness or dryness of the plant material (Aregheore, 2002). ADF measurements at different stages of development in *Leucaena* studies showed variations from as low as 18 g/100 g of dry matter (Wheeler *et al.*, 1994) to as high as 42.2 g/100 g of dry mature in mature leaves (Nyambati *et al.*, 1996). In seedpods of *L. leucocephala* and *A. brevispica* crude protein was found to decline and fibre (NDF and ADF) to increase with maturity (Nyambati *et al.*, 1996).

Leaf samples of *Leucaena* collected from Three Rivers, Texas (USA) showed variations of *in vitro* digestibility ranging from 52.2 to 72.3 g/100 g of dry matter (Felker *et al.*, 1999). However, a majority of researchers have reported much lower values of *in vitro* digestibility for *Leucaena.* For example, Karachi and Zengo (1998) in Tabora, Tanzania, recorded values of 46.6 and 47.2 g/100 g of dry matter. In other countries, results of *in vitro* digestibility ranged from 48.6 to 64.7 g/100 g of dry matter (Nyambati *et al.*, 1996; Wheeler *et al.*, 1994).

Results of analysis for ash content, organic matter and ADL are much more consistent within species. The reported ash content of browse, including *L. leucocephala*, ranges between 5.4 and 11 g/100 g of dry matter, while organic matter values are between 89 and 95 g/100 g of dry matter (Aganga and Monyatsiwa, 1999; Mandal, 1997; Nyambati *et al.*, 1996; Stewart and Dunsdon, 1998). ADL, which is a measure of digestibility, reported by studies is very wide ranging among species but consistent within individual species. Values of 3.4, 10.1 and 9.2 g/100 g of dry matter in *Combretum apiculatum*, *Terminalia sericea* and *Euclea schimperi* have been reported in Botswana (Aganga and Monyatsiwa, 1999). ADL values of between 12.9 and 15.5 g/100 g of dry matter for *L. leucocephala* are reported in different countries (Karachi, 1998; Karachi and Zengo, 1998; Nyambati *et al.*, 1996).

Laboratory analyses of the mineral composition of browse feed are well established. The minerals of paramount importance are calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K) and sodium (Na). In most plants mineral content is influenced by soil nutrition. Na, K, P, Ca and Mg contents are reported by researchers to vary in studies of *Leucaena*, 0.001 to 0.01, 1.27 to 2.94, 0.12 to 0.24, 0.42 to 2.36 and 0.27 to 0.50 g/100 g of dry matter (Felker *et*

al., 1999; Karachi and Zengo, 1998; Karachi *et al.*, 1997; Tudsri and Kaewkunya, 2002). In Botswana browse analysis has produced mineral content values for Ca, Mg and P of 0.63, 0.24, and 0.14 g/100 g of dry matter for *A. galpinii* and 0.41, 0.16 and 0.26 g/100 g of dry matter for *F. albida* (Aganga *et al.*, 1999).

2.6 GROWTH RATES OF RUMINANTS

2.6.1 General

Chemical analysis in the laboratory provides an essential indication of forage quality for evaluating browse species to assess their suitability for planting. Although time consuming, it allows an initial evaluation of a wide range of exotic and indigenous trees which are candidates for agroforestry plantings, as well as constituting a more cost- effective way of establishing the value of trees before planting. However, the value of such browse can only be verified by ascertaining its contribution to the growth rates of animals (Norton 1994; Shelton, 1998).

2.6.2 Browse Contribution to Livestock Production

Documentation of the contribution of browse to the growth rates of cattle and small livestock (sheep and goats) has been carried out in several semi-arid countries where trees play a significant role in feeding livestock. As a potential solution to the problem of resource-poor farmers, the performance of animals fed on browse has in some cases been compared to that of animals given commercial feed and well known supplements such as *Medicago sativa* and *Lablab purpureus*.

Cattle fed with *Leucaena* leaves and grazed on pastures on which *Leucaena* is grown in Central Queensland were found to achieve daily weight gains of 800 g/head (Larsen *et al.*, 1998) without affecting carcass quality. In semi-arid Central Kenya, Nyambati *et al.* (1996) studied the mass gain of calves fed *A. brevispica* and *L. leucocephala* seed meal, each supplying 265 g crude protein daily, with the control group fed wheat bran. Mass gains of 486, 250 and 239 g/calf/day were recorded for *L. leucocephala*, *A. brevispica* and the control group respectively. In their

second trial calves fed *Leucaena* seed meal achieved significantly greater ($p<0.01$) daily increases in mass than both the control group and the calves fed *A. brevispica*. Average daily gains of animals fed *A. brevispica* seed meal were not significantly different statistically ($p>0.05$) from those of the control group because *A. brevispica* pods contained less than 65% seed, which is a major determinant of energy in pods, while *L. leucocephala* seedmeal had 100% seedpods. Equally important is the fact that a higher tannin content, which inhibits protein absorption, is found in seedless pods and may have been an inhibitor to crude protein utilisation (Nyambati *et al.*, 1996). In the second trial of their investigation, *L. leucocephala* seedpod meal with 80% seed produced a mass gain of 559 g/d in calves compared to the control group's value of 276 g/day. This suggested a minimal seed content (65%) is required in the pods as they are determinants of the level of protein when pods are used as supplement in livestock nutrition. The mass gains were significantly different ($p<0.01$) between the two diets (Nyambati *et al.*, 1996).

A study conducted in Botswana (Aganga and Monyatsiwa, 1999) showed that goats fed on supplements of *T. sericea, E. schimperi* and *C. apiculatum* gained 64 ± 9, 67 ± 19, 77 ± 15 g/goat/day respectively, compared to 78 ± 5 g/goat/day for those fed on *M. sativa* as a supplement. The results showed no significant difference ($p>0.05$) between the four feed supplements, but indicated that all species had the potential to meet the protein needs of goats (Aganga and Monyatsiwa, 1999).

At the University of Zimbabwe, studies of four browse species, *Acacia angustissima, Calliandra calothyrsus, Cajanus cajan* and *L. leucocephala,* fed to sheep at levels of 0, 50, 100 and 150 g dry matter/day/sheep, were carried out (Masama *et al.,* 1997). Total dry matter intake by the sheep increased significantly ($p<0.05$) with the increased levels of browse feed, except for *C. calothyrsus*. Digestibility of dry matter also increased significantly ($p<0.05$) with increasing levels of feed. The mass gain of sheep increased with an increase in dry matter intake but was not significantly different between sheep fed the four browse species (Masama *et al.,* 1997).

In studies conducted by Shenkoru and Mekonnen (1994) at Debre Zeit, Ethiopia, an increase in the level of *Leucaena* from 0 to 300 g/sheep/day increased the daily mean mass gains of the

sheep. The mean mass gains at different levels of feed were 59, 72, 73 and 87 g/sheep/day for 0, 100, 200 and 300 g/day of *Leucaena*. Their study indicated very significant contrasts between the four groups (Shenkoru and Mekonnen, 1994).

A study on the growth of menz sheep supplemented with three browse species, *Desmodium intortum*, *Stylosanthes guianensis* and *Macrotyloma axillare*, at 250, 350 and 450 g/sheep/day, and with maize stover as the control, was conducted in Addis Ababa, Ethiopia (Said and Tolera, 1993). The results showed increased dry matter (DM) intake with higher levels of browse for all three species. Significantly higher ($p<0.05$) dry matter intake of both hay and browse was observed in sheep fed *S. guianensis* and those fed *D. intortum*. Much lower total dry matter intake and nitrogen retention was observed in sheep fed *M. axillare*. The mean body mass gain was significantly higher in sheep fed *D. intortum* and *S. guianesis* than those fed *M. axillare* (Said and Tolera, 1993).

In Tabora, Tanzania, the growth rate of goats fed *L. leucocephala*, *C. cajan* and *S. sesban* showed a significant improvement ($p<0.05$) compared to those of a control group dependent on the natural grazing (Karachi and Zengo, 1998). In this trial trypanosomiasis (*nagana)*, i.e. a form of sleeping sickness in animals, affected goats in the control group more severely than those supplemented with browse. The control group lost more mass and showed symptoms of infection by losing mass earlier than the browse groups. The control group also continued to lose mass for a longer period than the supplemented animals following treatment (Karachi and Zengo, 1998).

3.0 MATERIALS AND METHODS

3.1 DESCRIPTION OF TRIAL SITE

3.1.1 Location and Size

Malotwana silvopastoral trial was established in November 1993 at Malotwana Village, Kgatleng District. The village lies at latitude 24° 20' S, longitude 26° 05' E and falls between altitudes 940 and 950 m. a.s.l.

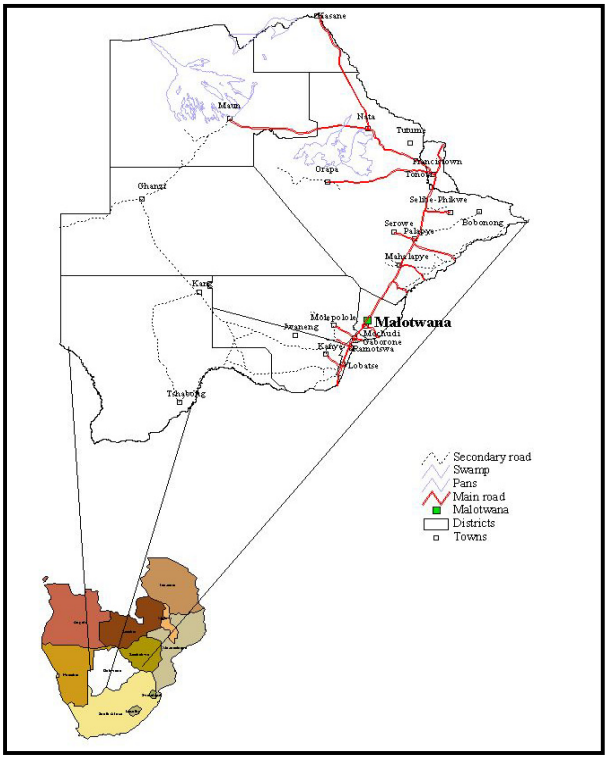


Fig. 3.1 Location of the study area

The trial plot measured 4.8 hectares on slightly sloping land with a down gradient 1.5 – 5% towards the north-east. The effect of the gradient is obvious during episodes of very intense rainfall which, as in much of eastern Botswana, are common in Malotwana. Under such conditions considerable soil erosion occurs and soil particles and nutrients are moved towards the north-east despite the high infiltration capacity of the sandy soils.

3.1.2 Climate

The village of Malotwana is a minor settlement and lacks full climatic records. The annual temperature range is approximately 12^{o}C but extremes of temperature are marked, with daily minima which can be as low as -4^{o}C in June and July, whereas daily maxima in summer may exceed 40^{o}C. However, occasionally cyclonic conditions can lead to considerable temperature falls to as low as 5^{o}C in the early summer season which may affect animal feeding behaviour. Maximum and minimum temperatures recorded at the Department of Agricultural Research Station (latitude 24 ^{o} 34' S, longitude 25 ^{o} 57' E; altitude 994 m a.s.l.), 40 km from Malotwana, between September 2001 and December 2001 are presented in Appendix 1.

The rainfall year in Botswana (from which annual totals are derived) runs from 1St July to 30th June. However, since the great majority of rainfall occurs between September and May inclusive which corresponds to the growing period, rainfall values in this study are frequently given as "seasonal rainfall", corresponding to the precipitation received over this period of the year.

Rainfall in Botswana is highly variable both from year to year and within any individual wet season. Similarly, in any one season rainfall is unevenly distributed throughout the country and can be very localised. Rainfall was recorded at the site during the seven years of the trial using the standard 5 inch rain gauge. The results are presented as a bar chart (Appendix 2, Fig. 1).

3.1.3 Soil

Soil samples specific to the area were taken at five locations at a depth of 30 cm for the preliminary assessment. These were described on-site and sent to the Department of Agricultural Research laboratory for analysis to establish soil organic matter, fertility and pH (pH data using both H_2O and CaCl). The soil at the site varied in pH (H_2O) between 5.15 and 5.72. The preliminary soil information was the basis for the application of kraal manure and agricultural lime.

Detailed soil samples were collected in each of the 60 plots at the end of the 6.5 year study to further investigate the performance of trees in different blocks from observations made during growth and upon data analysis. For this, samples were collected at five locations in each of the 32 x 25 m plots, at depths of 30, 60 and 100 cm using a soil auger. The samples for each plot depth in each block were mixed thoroughly and approximately 1 kg contained in a sample bag. The 180 soil samples (12 plots x 5 blocks x 3 different depths) were sent to the Department of Agricultural Research for analysis of pH, CEC, N, Na, Ca, Mg, C, P and K. A summary of the results is presented in Appendix 3.

3.2 ESTABLISHMENT OF TREES

3.2.1 Seed Acquisition

The indigenous tree seeds were acquired from the Forestry Association of Botswana (FAB) seed store. *A. galpinii* seeds were collected along the Makopo River in Shoshong, (latitude 23^{o} 02' S, longitude 26^{o} 30' E; altitude 1213 m a.s.l.; mean annual rainfall 500 mm). The *F. albida* seed was collected from the Tuli Block farm area (latitude 23^{o} 04' S, longitude 27^{o} 47' E; altitude 750 m a.s.l.; mean annual rainfall 450 mm).

The *L. diversifolia* and *L. leucocephala* seeds used in the trial were obtained from the Agricultural Research Council – the Roodeplaat Grassland Institute in Lynn East 0039, Republic of South Africa. The *L. diversifolia* seeds were issued as Prime No. 01U1, a Mexican ecotype collected above 2000 m and relatively cold-tolerant. *L. leucocephala* seeds used were K8 Prime No.01TF and some K28 Prime No.1V1 ex Tim Fenn.

3.2.2 Raising of Seedlings

Seedling production was commissioned from the FAB. Potting soil for the project was collected at the base of Kumakwane hill using a truck. The soil largely comprised decomposed leaf mould and was separated from raw plant material using a 10 mm sieve at the FAB Kumakwane nursery site. Potting was carried out in the first week of August 1993 using one-litre polythene bags. The indigenous trees were seeded on 5th and 6th August 1993. Seeds of *A. galpinii* were treated

by immersing them completely in near-boiling water and soaking them for 24 hours, while *F. albida* seeds were soaked in tap water for 24 hours. Seeds of *L. diversifolia* and *L. leucocephala* were treated by immersing them in near-boiling water and leaving them to soak overnight and sown between 15th and 17th August 1993. Seeding was carried out at the rate of three seeds per pot. Germination occurred between 10 and 14 days after sowing. Seedlings were thinned to one seedling per pot at approximately three weeks after emergence. They were watered once a day up to the end of October 1993 while under 60% shade netting. They were moved to a 40% shade net area in the first week of November and were watered three times a week until a week prior to planting. One week before field planting the seedlings were moved out of the shade net area for hardening and were watered three times in that week. Seedlings collected at the nursery were selected to be approximately the same height. The indigenous trees, *A. galpinii* and *F. albida,* were approximately 30 cm while the exotic *L. diversifolia* and *L. leucocephala* were approximately 40 cm tall.

3.2.3 Land Preparation

The land was destumped of vegetation. Following tree removal, well decomposed pig kraal manure was transported to the site using seven tonne trucks and dumped, one at the edge of each block, prior to the planting of seedlings. The trial plot was ploughed and harrowed to remove the roots of *T. sericea* two weeks before the planting of seedlings. The trial plot was pegged out according to the plot layout.

3.2.4 Planting

Two days before planting the seedlings were moved in a trailer covered with a shade net and were watered upon arrival on site to reduce heat stress. Planting holes for each tree were 40 by 40 cm wide and 40 cm deep. The topsoil from the hole was mixed thoroughly with approximately 1 kg of decomposed pig manure and 20 g of agricultural lime and applied per hole. A basin of approximately 50 cm radius was created around the planted seedling to accommodate the soil mixture of lime and kraal manure and to create a catchment for rain water during planting. Planting was conducted over two days on 20th and 21st November 1993.

Saplings were watered with potable borehole water using a 10 litre bucket for each plant. At planting a diluted organochlorocarbon ant killer was applied to each seedling before watering to control termites.

Replacement of dead seedlings was carried out two weeks after planting. At this stage it was also necessary to apply pellets of Carbaryl (Kamikaze) because harvester termites were attacking the seedlings.

3.3 EXPERIMENTAL DESIGN

The design was a 4 x 3 factorial experiment in a Randomised Complete Block Design. The main factors were the four tree species, *A. galpinii*, *F. albida*, *L. diversifolia* and *L. leucocephala*, and the three spacings, 5 x 5, 6.3 x 5 and 8.3 x 5 m, replicated five times. Each block had twelve plots measuring 25 by 32 m (0.08 ha). The plots were randomised within each block by balloting the species and spacing into plots in the sequence of plots 1 to 12.

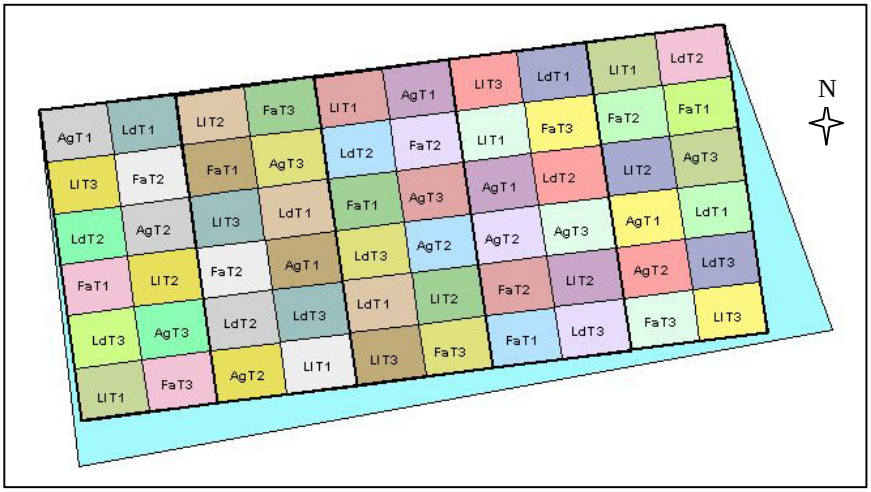


Fig. 3.2 Experimental lay-out

A.g = A.galpinii F.a = F. albida L.l = L. leucocephala L.d = L. diversifolia

High T_3 = 400 trees ha^{-1} Medium T_2 = 317 trees ha^{-1} Low T_1 = 241 trees ha^{-1}

The density of 400 trees per hectare was based on the average spacing of indigenous trees in their natural stands by the rivers. The 317 and 241 density stands were then selected because of the poor soils and low rainfall characteristic of the trial site (Appendix 3). This would reduce competition for both nutrients and water in the arid environment of Botswana. The spacing of exotic trees was pegged to that of the indigenous to allow a fair comparison with the performance of both sets of species in the on-farm evaluation under arid conditions.

There were eight trees in a T_1, 12 in a T_2 and 16 in a T_3 plot. The number of trees in a hectare was estimated by calculating the area in which individual trees in each spacing theoretically exploited nutrients. In a plot with spacing of T_1 each tree had a theoretical area of 8.3 x 5 m = 41.5 m^2 giving a theoretical density of approximately 241 trees per hectare. Each T_2 plot had an area of 6.3 x 5 m = 31.5 m^2 giving a density of 317 trees per hectare. With T_3 spacing each of the 16 trees occupied an area of 5 x 5 m = 25.0 m^2 with tree density of 400 trees per hectare.

3.4 PLANT MANAGEMENT

3.4.1 Watering

The frequency of watering was determined by rainfall. Appendix 2, Figure 1 shows growing season rainfall (September to May) during the study period. At each watering ten litres of water was applied per plant. The first application was made at time of planting at the end of November 1993. During the first six months until the end of May 1994, when the first assessment took place, plants were watered two or three times per month for a total of 15 times. A total of 144 m^3 of water was used in this period with each tree receiving 150 litres. For the following months (June to September 1994) the indigenous trees were watered once a month leading to a usage of 19.2 m^3 or 40 litres per tree.

The exotic tree species were watered during the dry season at fortnightly intervals from June to September throughout the study and immediately after every complete plant harvest. The first complete plant harvest was at the data collection of May 1996 when trees were aged 2.5 years. Thereafter complete plant harvesting was done every two years at the end of the wet season, i.e.

in May 1998 and May 2000. A total of 264 m^3 of water was used to irrigate the exotic species between September 1994 and completion of the trial in May 2000 corresponding to 550 litres per tree.

3.4.2 Weeding

After planting in November 1993 plots were clean-weeded in February 1994. Thereafter weed control was carried out annually in November or early December by ploughing the trial area between trees to a depth of 15 cm (Plate 1). The basins around the tree were renewed for water catchment and the rows between indigenous trees were clean-weeded. The plots were subsequently weeded twice along rows during the rainy season.

Plate 1 Ploughed field for weed control L. diversifolia *plot (1999).*

Plate 2 A. galpinii *ploughed before row weeding (1999)*

3.5 DATA COLLECTION AND MEASUREMENTS FOR THE STUDY

3.5.1 General

There were four sets of data collected in this study, i.e. indigenous tree assessment, exotic tree measurements, nutritional analysis and growth lambs fed browse. Data collection investigating the performance of the indigenous trees was carried out at 0.5, 2.5, 4.5 and at 6.5 years. Data collection for the exotic trees was carried out at the end of six months and thereafter at 1.5, 2.5, 3.5, 4.5, 5.5 and 6.5 years. The data collection for plant nutrient analysis was carried out at the

end of the study period in May 2000. The data collection assessing the growth rates of lambs fed fodder from exotic trees was carried out between September 2001 and January 2002.

The following equipment was used in taking tree measurements: a 10 m tape for measuring crown width, a vernier caliper for measuring stem diameter, and a staff to measure the height of trees. A Hansen bathroom scale was used to record wood yield and mass of the lambs. Pod and leaf mass was determined with a kitchen scale and an electronic scale was used for oven dry matter measurements. Sticks measuring 1.3 m and 50 cm were used to indicate the heights at which stem diameters of indigenous and exotic trees respectively had to be measured.

3.5.2 Data Collection of Trees Six Months after Planting

The first data collection was carried out at the end of the wet season, six months after planting (May 30-31st 1994). Data collection involved assessing survival percentage per treatment plot and measuring tree height and crown width for all four species. Tree height was based on the tallest shoot and crown width determined by the mean of the north-south and the east-west plant crown measurements. The four most central trees in each plot were assessed during all data collections.

3.5.3 Data for Indigenous Trees

The *A. galpinii* and *F. albida* data collection involved measurements of height, diameter at breast height and crown width. Stem volume index was calculated through the equation: mean dbh^2 x height x stem number. After the 1994 data collection, measurements were carried out in 1996, 1998 and 2000.

3.5.4 Data for Exotic Trees

3.5.4.1 Annual Data Collection

Data for exotic trees were collected annually in 1994, 1995, 1996, 1997, 1999 and 2000 at the end of May with a view to comparing the performance of the two *Leucaena* species under the three spacing treatments. Measurements involved crown width, height, stem diameter at 50 cm, and stem number or the number of coppice shoots. Stem volume index was obtained through the equation: SVI = mean $Stdm^2$ x ht x Stno.

SVI = stem volume index

$Stdm^2$ = Stem diameter at 50 cm squared

ht = height

Stno = Stem number

3.5.4.2 Complete Plant Harvest

The season 1994 to 1995 was used to observe the response to climatic conditions in order to determine the appropriate time for pod collection. The first complete plant sampling was conducted at the end of the wet season in May 1996, i.e. when trees were aged 2.5 years. After this, complete harvesting was carried out eighteen months after the previous harvest, in 1998 and 2000. Plant harvesting involved cutting each of the four measured trees in the centre of the plot at the base (approximately 5-10 cm above ground) and separating the tree into leaf, pod and wood samples. Masses were recorded per individual tree, immediately after separating. Where flowers occurred, they were added to the pods. In each year of complete plant sampling the pod mass from the season's collection was added to the final pod mass from the complete plant sampling to calculate the total wet mass.

Two to three pod harvestings, including the final collection destructive sampling, were carried out during the wet season for *L. leucocephala* and two for *L. diversifolia*. The number of collections in the season was determined by the onset of the rain and the length of dry spells between periods of rainfall. When the rainfall season started in October and falls were relatively

evenly distributed, seed maturity was in December or early January and the final collection in May with the rest of data collection. When the year was dry, close monitoring of seed was required and three collections were carried out.

Pod and leaf oven-dry matter were calculated by weighing the green mass of pod and leaf samples before and after oven-drying at 70^{o}C for nutritional analysis and then calculating the percentage DM for these samples. The percentage dry matter of pods (29%) and leaves (36%) was used to convert the green mass data obtained at harvesting to a dry matter basis for all the years.

3.5.4.3 Wood Dry Matter

The wood dry matter was determined by weighing bundles of fresh wood from each tree at harvest, recording the mass, and then tagging the bundle with a paper label. The labels were covered in plastic to avoid them being smudged during rain. The wood bundles were then sun-dried, with some bundles being used to test the state of dryness for their use as firewood. This was modelled on the basis that traditionally Batswana use dry wood. Well dried wood burns without spitting gum-like material (*kgakgamosi*) and emitting black smoke. Burning properties were tested every two weeks, but also of importance was the monitoring of attacks by the woodborer whose activity can affect the wood dry mass measurements. Where stock borer attack had occurred the previous week mass was used instead of the current mass. The mass of dry wood was recorded when measurements over two successive weeks were similar. Calculated dry matter of wood was 70% of fresh mass which was used to convert to dry mass.

3.6 NUTRITIONAL ANALYSIS OF AGROFORESTRY PRODUCTS

3.6.1 Sampling of Plant Material

At the final data collection in May 2000, after recording the fresh mass of leaves per tree, leaf material was mixed thoroughly per plot and 250 g was placed in a sampling bag for oven drying. Leaf material was also collected from the four most central indigenous trees in each plot which

were measured throughout the study and mixed thoroughly before 250 g was taken for oven drying and processing. A total of 60 leaf samples from the trial were dried to facilitate the measurement of digestibility in terms of ADF, NDF, IVDMD, ADL and for the minerals Ca, Mg, K, P and N. Crude protein was calculated by multiplying the nitrogen percentage by 6.25 (AOAC, 1996).

Pod samples were collected from the 30 plots of *L. diversifolia,* and *L. leucocephala.* from the same trees from which all previous measurements had been taken. For both pods and leaves the samples were labelled carefully and dried in a forced-fan air oven at 70^{o}C for 48 hours.

Oven-dried plant material was ground, using a stainless steel mill, and passed through a 1 mm sieve. The processed material was labelled and stored in airtight plastic jars, until taken for *in vitro* dry matter digestibility, fibre digestion and mineral analysis. From each of the 60 sampled plots of leaves five runs per sample were weighed making a total of 300 samples. For the 30 plots with pods, with five runs there were 150 samples. Hence a total of 450 samples were analysed.

3.6.2 Chemical Analysis

Nutritional analysis was carried out according to the methods of the Association of Official Analytical Chemists (AOAC, 1996). The analysis was carried out at the Botswana College of Agriculture laboratory. The analysis involved measurements of NDF, ADF and ADL according to the modified Van Soest *et al.* (1991) procedure in the ANKOM^{220} fibre analyser.

The condensed tannin contents of the leaves of all four species and the pods of the two exotic trees were determined using the procedures of Makkar (1999) and involved the ultrasonic water bath extraction of tannin. The solvent aqueous solution was 70% acetone and 30% distilled water, butanol-HCL reagent and ferric solution. The measurements were taken using a spectrophotometer.

The AOAC (1996) manual procedure was followed in analysing ground materials which were digested in a Kjeldatherm Gerhardt digestion block. A Gerhardt Vapodest distillation titrator was used to determine the nitrogen percentage. The digest was used for analysis of the minerals calcium (Ca) and magnesium (Mg), using an Atomic Absorption Spectrometer (GBC 908 AA). A flame photometer (Ciba-Corning Flame Photometer 410) was used to measure sodium (Na) and potassium (K) as described by AOAC (1996). Phosphorus (P) was measured using a UV1601PC UV visible spectrometer (ILSA (Pty) Ltd). Organic matter (OM) and ash were determined by ashing samples in a Gallenkamp muffle furnace at 550^{o}C for four hours. *In vitro* dry matter digestibility was measured following the modified technique of Tilley and Terry (1963). The rumen fluid was obtained from a fistulated cow from the Department of Agricultural Research Station in Sebele, Gaborone, Botswana.

3.7 ANIMAL SELECTION, FEED, MANAGEMENT AND MEASUREMENTS

3.7.1 Selection of Parent Ewes and Selection of Experimental Lambs

Fifty dorper ewes of known background and pedigree were identified from the researcher's kraal as breeding stock in December 2000. This was mid-summer and, in general, maximum temperatures ranged from 36 to 38^{o}C with minima 18 to 20^{o}C. Summer mating allows births to take place with winter coming to an end; this generally ensures that by the time lambs graze, there is adequate vegetation. The parent ewes had been sired by the same ram and were without serious sickness records. They had lambed either once or twice previously. The ram used to sire the experimental animals was purchased to avoid inbreeding and served the 50 ewes from mid-December 2000. Fifty-three lambs out of the group were born between June 4th and July 7th 2001 and each was tagged and numbered on the basis of its date of birth.

From the 50 lambs, eight lambs were randomly selected on 19th September 2001. The second eight lambs were selected to be balanced for mass and sex between the control group and the browse group. The mass of the 16 selected lambs ranged from 13.5 to 20 kg and the mean masses were 16.04 ± 0.79 and 16.04 ± 0.53 kg for the browse and control groups respectively.

The lambs were penned in adjoining shelters where the environmental conditions for the two groups were similar. They were weighed individually and the mean mass of the eight animals used as the basis for comparison of the effects of the two feed units (Steel and Torrie, 1980).

The animals were intravenously vaccinated against pasturella at 2 ml per animal and pulpy kidney using pulvax at 1 ml per animal. This was followed by de-worming with Zenfen (Ahbenvasole 2.5%) at a dose of 5 ml administered orally. The lambs were all given vitamins A, D and E anti-stress at 1 ml per animal intramuscular prior to the trial. Veterinary surgeons from the Botswana College of Agriculture gave the selected lambs a health examination before the feeding programme commenced (Plate 3).

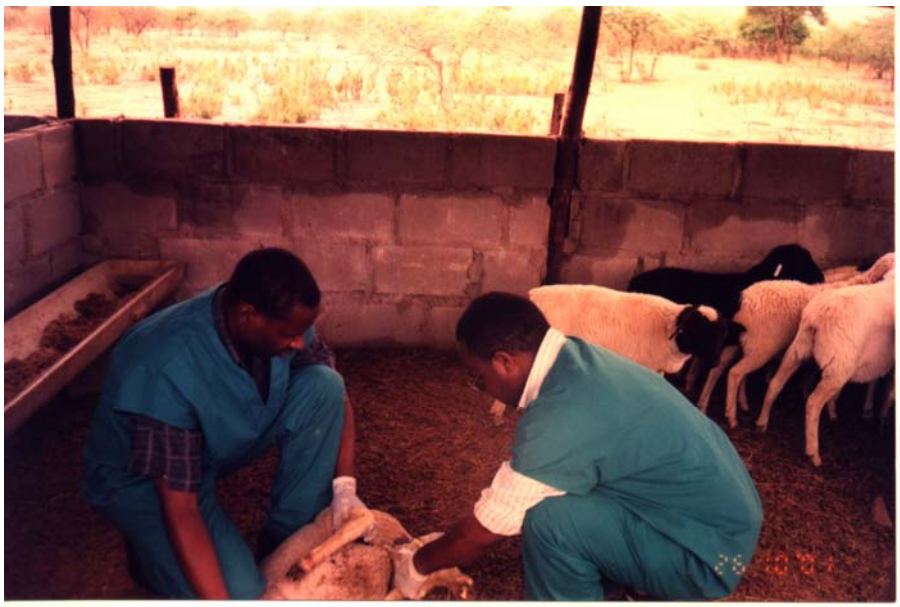


Plate 3: Veterinarians examining lambs before the feeding

Two sick lambs in the control group were each given mildox 1ml, intramuscular, three days after the trial started, plus 5 ml Phosmine and 0.5 ml Ivomectin on days 1 and 14 of the monitoring. The feed trial was conducted for 134 days, including 14 days for feed adjustment and 120 days of feeding trial. This led to final mass at 6-7 months, i.e. the age at which female animals are sold for breeding and castrated males are at the selling mass of approximately 28 to 30 kg.

3.7.2 Feed Accessing and Processing

3.7.2.1 Feed Sources

The grass was accessed from the standing hay stock of the Department of Agricultural Research Station at Sebele. The sorghum bran was purchased from the TOM (Pty) Ltd. Milling Company, Mochudi, Botswana. Iodised salt and dicalcium phosphate were obtained from the Botswana Government Livestock Advisory Centre.

The grass, pods and leaves of the *L. leucocephala and L. diversifolia* were processed using a motorized Hippo hammer-mill with a sieve size of 15 mm. The browse feed was made up of two-thirds pods and one-third leaves of the two species in equal mass amounts. Pods and leaves used were from the final year of plant harvesting (2000).

3.7.2.2 Feed Quantities

The control group was fed 30% sorghum bran, 0.5% dicalcium phosphate, 0.5% iodised salt and 69% *Cenchrus ciliaris* (buffel grass). The treatment group was fed 30% sorghum bran, 30% browse feed, 0.5% dicalcium phosphate, 0.5% iodised salt and 39% grass. The animals were fed the rations *ad lib* with feed troughs being refilled when 10% of the feed remained. Water from the farm borehole was supplied *ad lib.* The rationale for feeding bran to the control group was to avoid losses of animals during the trial and also because it is the feed most readily available and most commonly purchased by farmers to support animals during drought periods.

3.7.3 Period of Measurements

Body mass was measured every week during the first five weeks using a Hansen bathroom scale, but subsequently weighing was carried out every two weeks up to the 19^{th} week including two weeks of adjustment to feed. Individual animals were weighed handheld and the mass of the person deducted. The basis for evaluating browse was the mean mass of the eight lambs in comparison with that of the eight lambs in the control group. Consequently the analysis of

variance was based on a paired t-test comparison of the two units for testing differences between masses.

3.8 COST-BENEFIT ANALYSIS

Cost benefit analysis of the feeding regime was estimated by valuing the lambs at weaning on the basis of their purchase price at the Botswana College of Agriculture farm. The cost of labour was arrived at by allocating the labour on the farm between the three activities of production: livestock care, guinea fowl rearing and tree management. However, labour for harvesting pods and leaves was regarded as an additional cost and based on the amount of feed used rather than the total harvest for that year. The cost of processing the grass for both groups was included in the bale cost which was increased from P10 to P12 per bale. Veterinary remedies were costed on the basis of doses per bottle, as the same products were used to treat the rest of the flock. Watering of trees was included under the farm casual labour cost over the whole of the study period. It must, however, be taken into account as a factor when it comes to recommending the practice.

3.9 ANALYSIS OF DATA AND STATISTICAL MODELS

The data for plant growth, nutritional analysis and animal growth were entered in Microsoft Excel and analysed using the SAS statistical package (2000). They were subjected to analysis of variance and means were separated using the Student-Newman-Keuls Test.

The analysis of tree performance was divided into two models. Model 1 compared the growth and performance of indigenous trees, while model 2 compared the growth and fodder productivity of the exotic species.

3.9.1 Model 1: Growth of Indigenous Trees over the 6.5 Years

Model 1 analysis involved the performance of indigenous species (*A. galpinii* and *F. albida)* trees and is described by the equation:

$Y_{ijk} = \mu + B_i + S_j + T_k + TS_{jk} + e_{ijk}$

Y_{ijk} = tree performance

μ = expected overall mean

B_i = variation effect due to the i^{th} block $i = 1, 2, 3, 4, 5$

S_j = effect due to the j^{th} species $j = 1, 2$

T_k = effect due to using the k^{th} spacing $k = 1, 2, 3$

TS_{jk} = the interaction due to the effect of the j^{th} species and the k^{th} spacing.

E_{ijk} = random error effect $\sim N(0,\sigma^2)$

- In this model only the two indigenous species (*A. galpinii*, *F. albida*) were compared in the analysis. Tree performance (Y_{ijk}) was measured every two years from 1994, using four variables: tree crown width, height and, from 1996 to 2000, the variables of tree crown width, diameter at breast height, and stem volume index.
- The model was fitted separately to each measure of performance, i.e. crown width, height, diameter at breast height and stem volume index.
- Separate analyses were carried out for each year of data collection, i.e. 1994, 1996, 1998 and 2000.

The relevant hypotheses of interest in the analysis of variance models were:

(1) H_{10}: No interaction between species and spacing (the best or worst species is independent of spacing and vice versa). Formally:

$TS_{jk} = 0$ for j =1, 2; k =1, 2, 3 vs. (1) H_{10} : $TS_{jk} \neq 0$ for at least one pair of (j,k).

(2) H_{20}: No species effect: $S_j = 0$ for all j vs. $H_{1:}$ $S_i \neq 0$ for at least one species.

(3) H_{30}: No spacing effect: $T_k = 0$ vs. H_1 : $T_k \neq 0$ for at least one spacing.

3.9.2 Model 2: Performance and Productivity of the Exotic Trees

The model compares the growth and productivity of the *L diversifolia* and *L. leucocephala* species over the study period of 6.5 years and the agroforestry products when complete plant harvesting was carried out. The specific analyses performed were as follows:

$Y_{ijk} = \mu + B_i + S_j + T_k + TS_{jk} + e_{ijk}$

Y_{ijk} = tree performance

μ = expected overall mean

B_i = variation effect due to the i^{th} blocks $\quad i = 1, 2, 3, 4, 5$

S_j = effect due to the j^{th} species $\quad j = 1, 2$

T_k = effect due to using the k^{th} spacing $\quad k = 1, 2, 3$

TS_{jk} = interaction due to the effect of the j^{th} species and the k^{th} spacing

e_{ijk} = random error effect, $\sim N(0, \sigma^2)$

In model 2, there were:

k = 1, 2, 3 corresponding to low (8.3 m), medium (6.3 m) and high (5.0 m) density spacings respectively. μ = stem number or the number of coppice shoots, height, crown width, stem diameter at 50 cm and stem volume index, oven-dried leaf and pod mass, air dried wood mass and total biomass. The number of species j = 2 comparing *L. diversifolia* and *L. leucocephala*.

The relevant hypotheses of interest in the analysis of variance models were:

(1) H_{10}: No interaction between species and spacing (the best or worst species is independent of spacing and vice versa). Formally:

$TS_{ij} = 0$ for j = 1, 2; k = 1, 2, 3 vs. $H_1 : TS_{ij} \neq 0$ for at least one pair of (j,k).

(2) H_{20}: No species effect: $S_j = 0$ for all j vs. H_1: $S_i \neq 0$ for at least one species.

(3) H_{30}: No spacing effect: $T_k = 0$ vs. H_1: $T_k \neq 0$ for at least one spacing.

- In this model, only the exotic species were included in the analysis. Furthermore, tree performance (Y_{ijk}) was measured annually from 1994 to 2000, using the seven variables:

crown width, height, stem diameter at 50 cm, stem/shoot numbers, leaf mass, pod mass, wood mass and total biomass.

- Data for the variables, leaf, pod and wood mass, were obtained following complete plant sampling at the three stages of 1996, 1998 and 2000, i.e. 2.5, 4.5 and 6.5 years after planting.
- Separate analyses were carried out for each year.

3.9.3 Model 3: Chemical Composition of Leaves of all Four Species

The form of the analysis of variance model for the nutritional analysis of leaves of the four species was:

$Y_{ijk}\,l = \mu + B_i + S_j + T_k + TS_{jk} + e_{ijk}$

Y_{ijk} = nutrient content

μ = expected overall mean

B_i = variation effect due to blocks $\quad i = 1, 2, 3, 4, 5$

S_j = effect due to the j^{th} species $\quad j = 1, 2, 3, 4$

T_k = effect due to using the k^{th} spacing $\quad k = 1, 2, 3$

TS_{jk} = the interaction due to the planting the j^{th} species at the k^{th} spacing

e_{ijk} = random error effect $\quad \sim N(0, \sigma^2)$

l = number of runs $\quad l = 1, 2, 3, 4, 5$

k = 1, 2, 3 corresponding to low (8.3 m), medium (6.3 m) and high (5.0 m) density spacings respectively.

- This model was similar to model 1, except that the data on the nutritional content of plants as discussed in section 3.6.1 were used as the dependent variable (Y_{ijk}).
- The nutritional content of each tree (Y_{ijk}) was measured using NDF, ADF, ADL, IVDMD, CP, Ca, Na and tannin.
- The analysis was done separately for each dependent variable.

3.9.4 Model 4: Chemical Composition of Pods and Leaves of Exotic Trees

The model was intended to determine whether the content of each element in the pods of the same plant species (exotic) differed significantly from that of the leaves of the same species.

- This model was used to compare the nutritional content of pods and leaves of the same species, the species being either *L. diversifolia* or *L. leucocephala.*
- The nutritional content of the part species (Y_{ijk}) was measured using NDF, ADF, ADL, CP, Ca, Na and tannin. Hence the studentised t-test was used, with the dependent variable (Y_{ijk}) being the amount of a given chemical in leaves (j = 1) or pods (j = 2) of the same species.

$Y_{ijk\,l} = \mu + B_i + P_j + T_k + P\,S_{jk} + PlB(P+T)_{ijk} + e_{ijkl}$

Y_{ijkl} = nutrient content

μ = expected overall mean

B_i = variation effect due to blocks i = 1, 2, 3, 4, 5

P_j = effect due to the j^{th} part j = 1, 2, 3, 4

T_k = effect due to using the k^{th} spacing k = 1, 2, 3

PT_{jk} = the interaction due to planting the j^{th} part at the k^{th} spacing.

$B(P*T)_{ijk}$ = random error, ~ $N(0, \sigma^2)$

e_{ijkl} = sampling error effect ~ $N(0, \sigma^2)$

l = number of runs l = 1, 2, 3, 4, 5 runs

k = 1, 2, 3 corresponding to low (8.3 m), medium (6.3 m) and high (5.0 m) density spacings respectively.

H_o: No difference between mean concentration of a given element in leaves and pods of plants of the same species: i.e. $H_o: \mu_1 - \mu_2 = 0$ vs. $H_1: \mu_1 - \mu_2 \neq 0$.

3.9.5 Model 5: Growth of Lambs

The model for analysing animal growth was intended to compare the effect of the two feeds on growth rates. As indicated in section 3.7.1 paragraph 3, the trough was the sampling unit.

$Y_{ij} = \mu + T_j + E_{ij}$

Y_{ij} = mass of lambs

μ = expected overall mean

T_i = feed effect i = 1, 2

E_{ij} = random error

j = number of lambs j = 1, 2, 3, 4, 5, 6, 7, 8

H_o: No difference between mean mass of browse-fed lambs and that of control group,

i.e $H_o = \mu_1 - \mu_2 = 0$ vs H_1: $\mu_1 - \mu_2 \neq 0$

4.0 RESULTS

4.1 PERFORMANCE OF INDIGENOUS TREES

4.1.1 General

The first measurements were taken six months after planting and involved survival percentage, crown width and height. The survival of *A. galpinii* was 99% and that of *F. albida* 98%. In both species these survival rates were maintained up to the age of 4.5 years when 67% mortality was experienced in *F. albida* due to drought.

The performance of indigenous trees for all parameters at different densities is presented in Appendix 4, Table 1, together with standard errors of the mean n = 20 except where indicated. The mean stem number of the indigenous trees was significantly different between species ($p<0.0001$); *A. galpinii* had two stems per tree (2.1 ± 0.10) compared to a lower value for *F. albida* (1.35 ± 0.08.).

Throughout the presentation the terms high, medium and low density are applied to stands in order to make comparisons of growth. As indicated in section 3.3, high density plots are spaced at 5 x 5 m, medium density 6.3 x 5 m, and low density at 8.3 x 5 m.

4.1.2 Crown Width

Figure 4.1 compares mean tree crown width between the two species. Throughout the period of the study n = 60 except for *F. albida* at the age of 6.5 years when n = 41. Mean crown width of *A. galpinii* increased steadily over the 6.5 years in contrast to *F. albida* where both dieback and high mortality led to lower values after the age of 2.5 years.

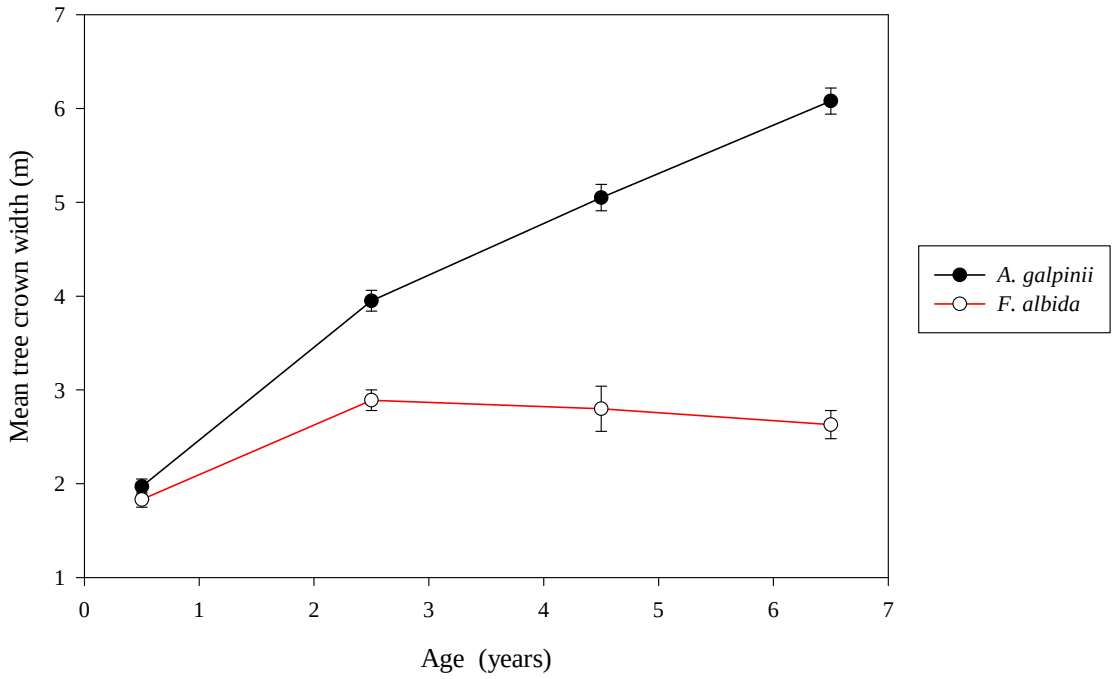


Fig. 4.1 Mean tree crown width of indigenous trees

n = 60 except for *F. albida* at 6.5 years n = 40

Analysis of variance results for crown width over the 6.5 years is presented in Appendix 4, Table 2. The results show that at the age of six months the difference between the species was not statistically significant (p = 0.2515). However, at the ages of 2.5, 4.5 and 6.5 years the difference between the two species was statistically significant (p<0.0001).

The mean tree crown width for *A. galpinii* and *F. albida* at different spacings over the four stages of measurement: 1994 (0.5), 1996 (2.5), 1998 (4.5) and 2000 (6.5 years after planting) are shown in Figures 4.2 and 4.3.

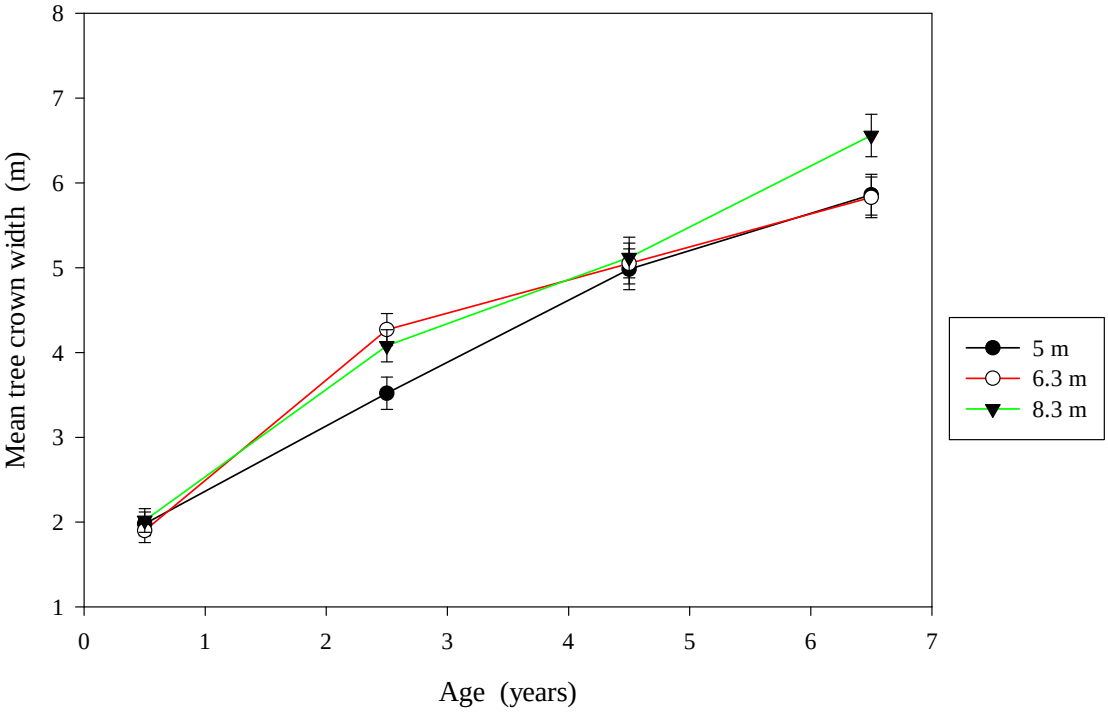


Fig. 4.2 Mean tree crown width of A. galpinii *at different spacings*

n = 20

The mean tree crown width for *A. galpinii* at different spacings (Fig. 4.2) did not differ six months after planting. When measurements were taken at the age of 2.5 years, medium density plots had the highest means. The growth of crown width in the medium density plots was almost constant between the ages of 2.5 and 6.5 years, but at a slower rate than it was from 0.5 and 2.5 years. In low density plots the mean crown width was initially lower than that of medium density stands, but increased at a greater rate than that of medium density plots between the ages of 2.5 and 6.5 years to become significantly bigger than in the high and medium density plots. It is worth noting that the crown width at high density was lower throughout the growth period than those of both low and medium density stands, except at 6.5 years when the value for high density plots was similar to that of medium density stands.

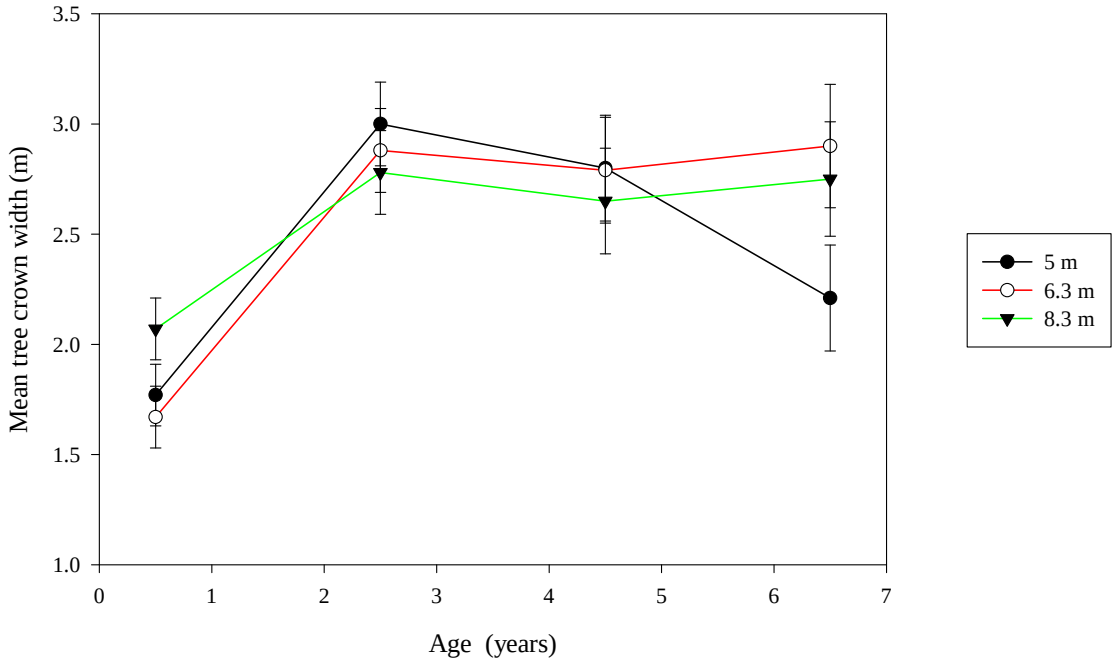


Fig. 4.3 Mean tree crown width of F. albida *at different spacings*

n = 20 except where as indicated in Appendix 4, Table 1,

crown width decreased due to die-back of branches and tree mortality

The mean tree crown width of *F. albida* over the 6.5 years of the study is presented in Figure 4.3. There was considerable variation in mean tree crown width at each stage of measurement.

The mean tree crown width of low density stands was similar to that of medium density plots both of which were significantly ($p = 0.0406$) greater than that in high density plantings at the age of 6.5 years (Appendix 4, Table 2).

Species x spacing interaction was statistically significant 2.5 years after planting ($p = 0.0452$). For *A. galpinii* the highest crown width was in medium density spacings and the smallest mean in high density plots. With *F. albida* high density stands had the highest mean and low density plots had the lowest value.

Plate 4 Regeneration of F. albida *December 1998 (trial site ploughed for weed control)*

Plate 4 shows a low density plot which experienced similar mortality to both medium and high density stands (Appendix 4, Table 1).

4.1.3 Height

Mean tree height increment of the indigenous trees for the period of the study is shown in Figure 4.4. At the age of six months, and up to the age of 2.5 years, *A. galpinii* achieved a greater mean height than *F. albida,* 1.53 ± 0.06 m compared to 1.24 ± 0.06 m, and 2.97 ± 0.07 m compared to 2.55 ± 0.07 m respectively.

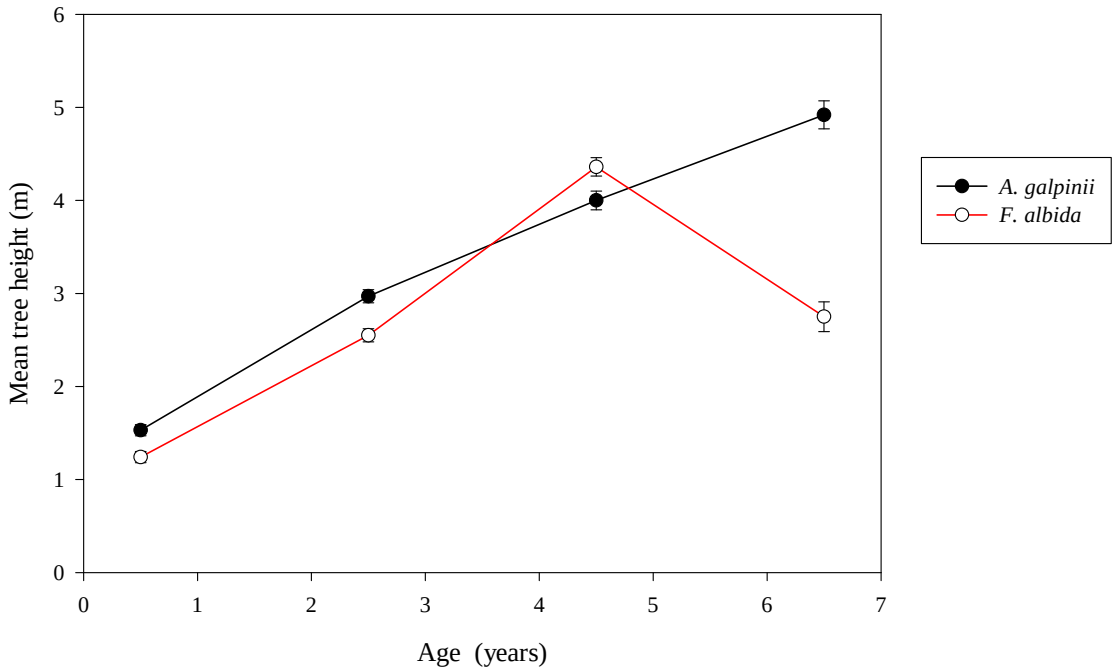


Fig. 4.4 Mean tree height of indigenous trees

n = 60 except for *F. albida* at 6.5 years n = 41

Measurement of trees aged 4.5 years showed a greater mean height in *F. albida* than for *A. galpinii*. However, while *A. galpinii* continued to gain height, the severe die-back and mortality of *F. albida* led to lower mean tree heights at the age of 6.5 years compared to both that of *A. galpinii* and that of *F. albida* when the trees had been aged 4.5 years. Trees that had die-back, resprouted during the seasons of 1998/1999 and 1999/2000. Appendix 4, Table 1 shows that the number of trees measured at age 6.5 years was fewer than at the previous data collections due to the fact that a third of the trees had died since the assessment at age 4.5 years.

Analysis of variance results are summarised in Appendix 4, Table 3. At the age of six months the difference in mean tree height between the two species was statistically significant ($p = 0.0006$). The difference between the species continued to be statistically significant over the period of the study, and at the ages of 2.5, 4.5 and 6.5 years p-values were $p<.0001$, $p = 0.0113$ and $p<.0001$ respectively.

The mean tree heights of *A. galpinii* and *F. albida* at different plot densities are shown in Figures 4.5 and 4.6.

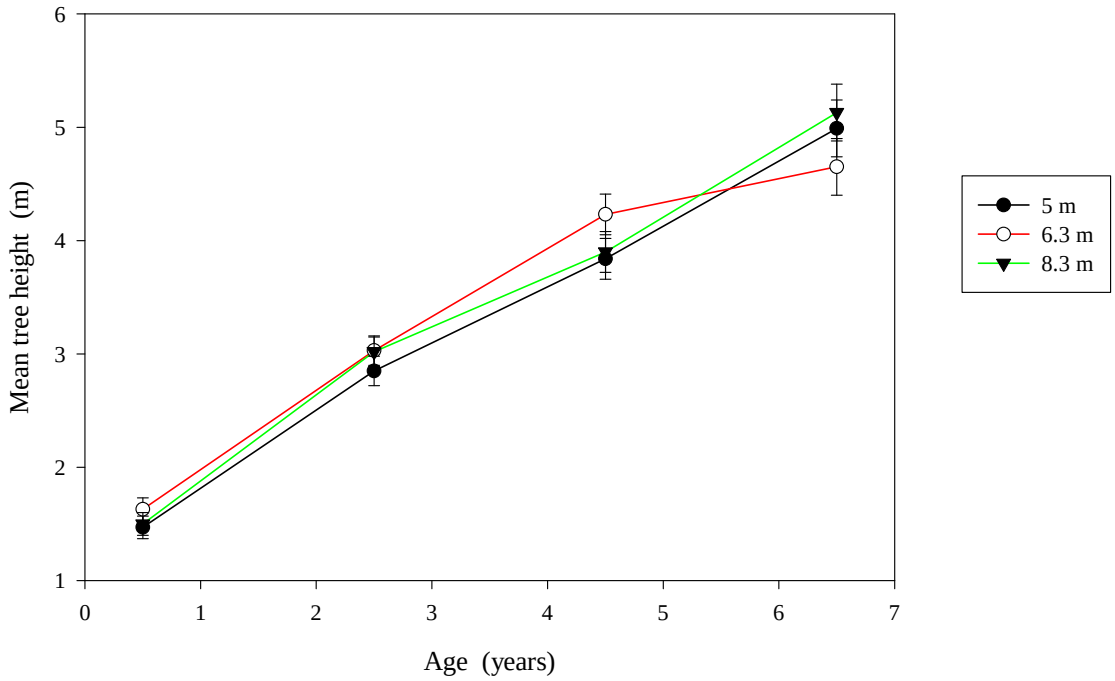


Fig. 4.5 Mean tree height of A. galpinii *at different spacings*

n = 20

The mean tree height increment of *A. galpinii* at medium density spacing was greater than those of trees in high and low density plots in most years (Fig. 4.5). However, at 6.5 years after planting, low density stands had the greatest mean height though not significant.

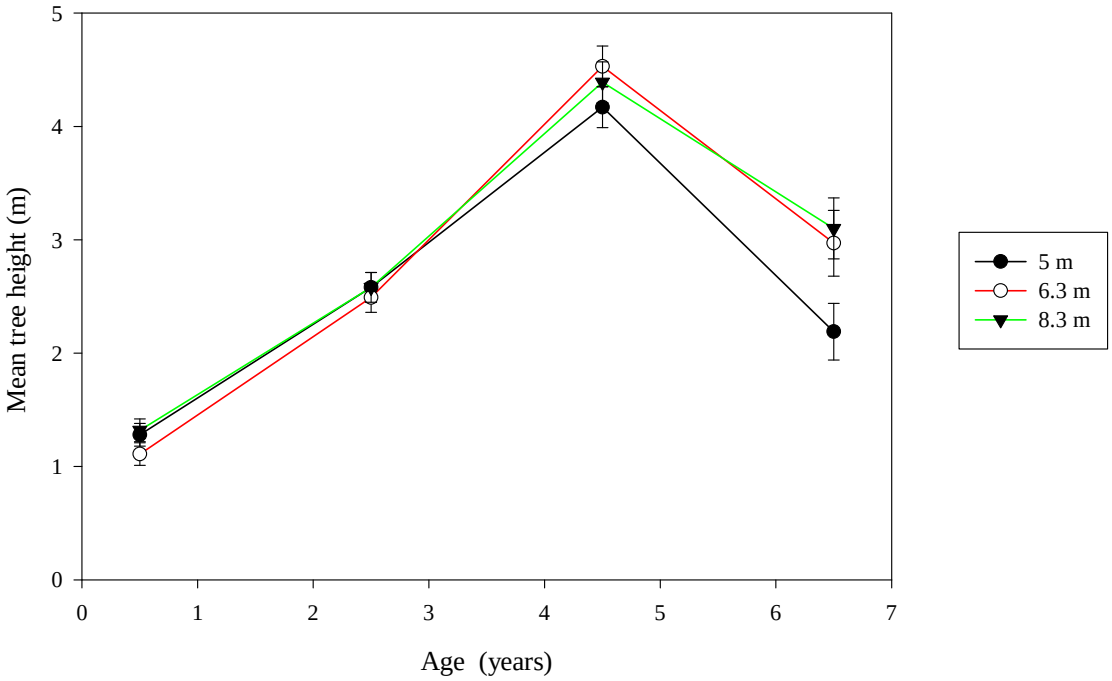


Fig. 4.6 Mean tree height of F. albida *at different spacings*

n = 20 except at 6.5 years n is shown in Appendix 4, Table 1

Good rainfall in the seasons of 1998/1999 and 1999/2000 led to resprouting of some *F. albida* following die-back and even mortality during the winter of 1998, the preceding rainy season 1997/1998 having received below average rainfall (Appendix 2, Table 1). As shown in Figure 4.6, *F. albida* mean heights at all planting densities were much lower at 6.5 years than those of trees aged 4.5 years, especially for high density stands.

The differences in mean tree heights among spacings were not significant throughout the study, as shown for Appendix 4, Table 3. Species x spacing interaction was not significant, but the p-value was 0.0980 for *A. galpinii* (Fig. 4.5) means were similar at contrasted spacings, while for *F. albida* (Fig. 4.6) mean of high density plots was considerably lower than those of both medium and low density at 6.5 years. At this age the mean heights of the trees at low and medium density did not differ significantly, but both values were bigger than mean height of trees grown at high density 3.10 ± 0.27 m compared to 2.97 ± 0.29 and 2.19 ± 0.25 m in medium and low density plots.

4.1.4 Diameter at Breast Height (dbh)

Comparative growth in diameter at breast height for the two species at different ages is shown in Figure 4.7. As with crown width and height, mean tree dbh of *F. albida* was lower at 6.5 years than at 4.5 years due to die-back that occurred after 4.5 years and the subsequent measurement of resprouting stems at 6.5 years.

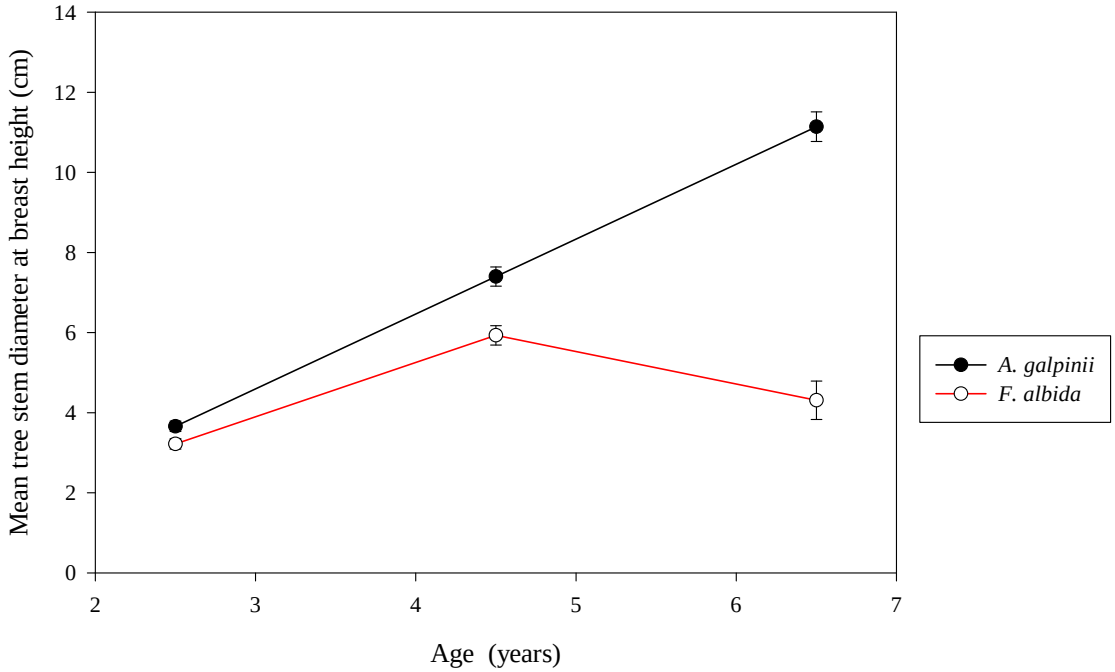


Fig. 4.7 Mean tree stem diameter at breast height of indigenous trees

Throughout the study the mean tree diameter at breast height of *A. galpinii* was greater than that of *F. albida*. The difference between the species was statistically significant ($p = 0.0283$) at the first dbh data collection when trees were aged 2.5 years and very highly significant ($p<0.0001$) at the ages of 4.5 and 6.5 years (Appendix 4, Table 4). The mean dbh of *A. galpinii* increased steadily, even in the drier seasons of 1996/1997 and 1997/1998 (Appendix 2, Fig. 1), while the die-back of *F. albida* (field observation) between the ages of 4.5 and 5.5 years influenced the results at the end of the study when its mean stem diameter was only 4.31 ± 0.48 cm due to partial resprouting, compared to 11.14 ± 0.37 cm for *A. galpinii* (Appendix 4, Table 1).

Increment in mean tree stem diameter at breast height (dbh) for *A. galpinii* at different densities is shown in Figure 4.8.

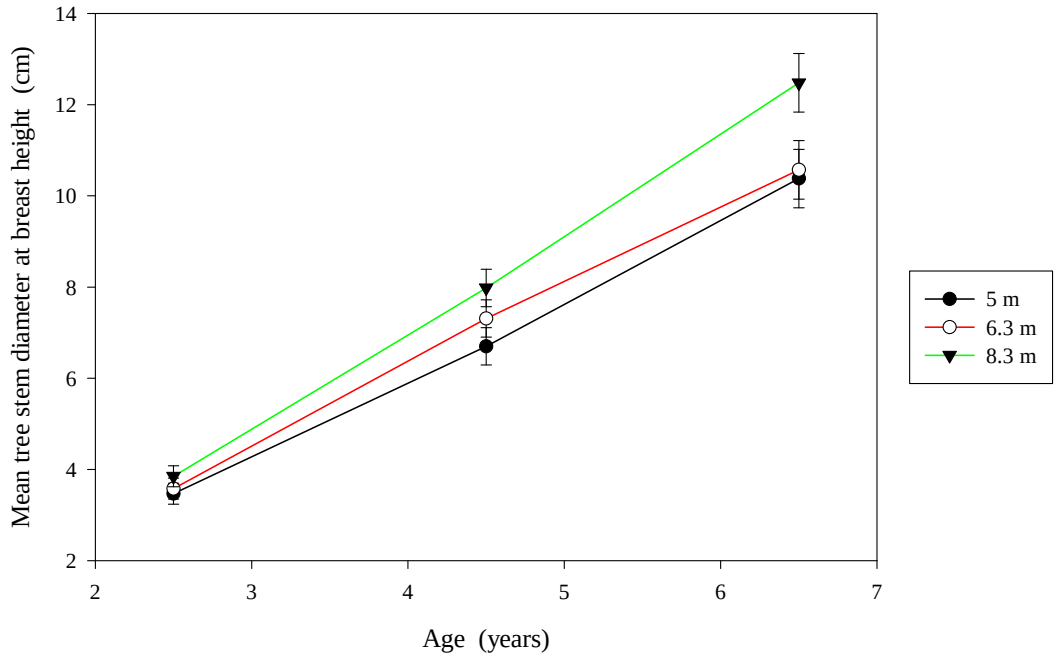


Fig. 4.8 Mean tree stem diameter at breast height of A. galpinii *at different spacings*

Throughout the study mean tree dbh was greatest in low density stands, followed by medium density plantings and with high density plots having the lowest mean.

The increment in dbh of *F. albida* is shown in Figure 4.9.

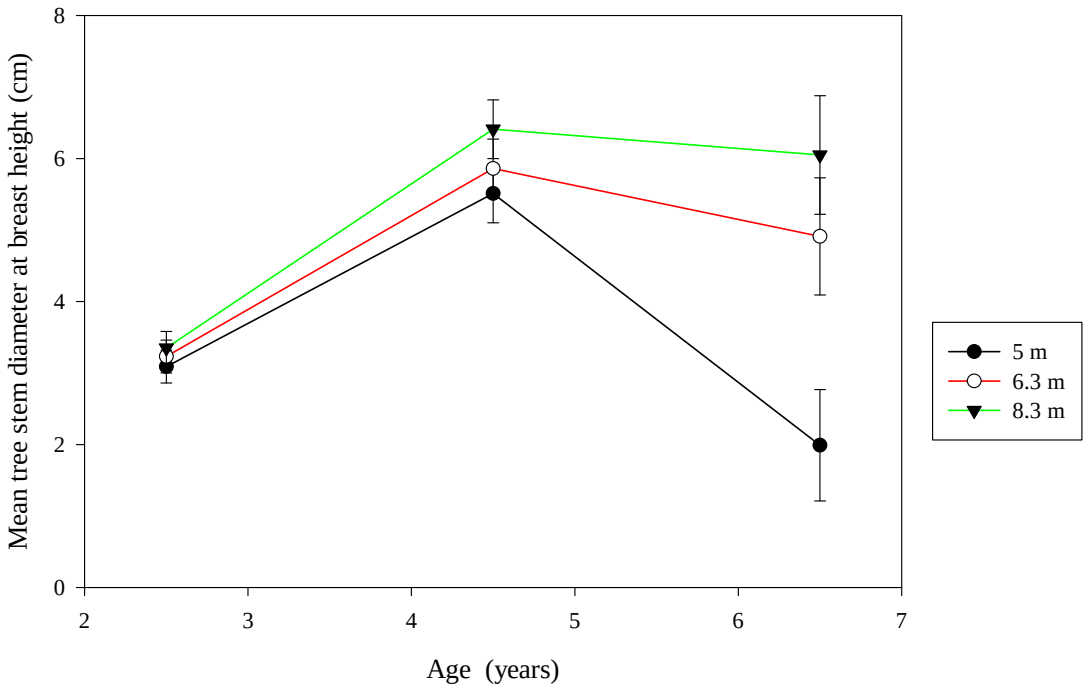


Fig. 4.9 Mean tree stem diameter at breast height of F. albida *at different spacings*

n = 20 except where indicated in Appendix 4, Table 1

The figure also shows the reduced diameter at breast height means at the age of 6.5 years compared to the age of 4.5 years due to most measurements relating to regeneration following high mortality. As with *A. galpinii*, trees in low density plots had the greatest mean tree dbh at all measurements, while high density plots had the lowest mean value.

Analysis of variance is shown in Appendix 4, Table 4. The difference in means at contrasting spacings was not significant at the age of 2.5 years for both species. However, the effect of plot density increased with the age of the trees, leading to significant differences in dbh. At the age of 4.5 years the differences were not significant, but the p-value was low ($p = 0.0567$) and the difference was statistically significant at the age of 6.5 years ($p = 0.0003$).

Species x spacing interaction was not significant (Appendix 4, Table 4). However, at the age of 6.5 years the mean value of *F. albida* trees at high density was distinctly lower than those of both

medium and low density plots, while for *A. galpinii* means of the trees at medium and high density were similar.

4.1.5 Stem Volume Index

Stem volume index is a factor of three parameters: height x mean dbh^2 x mean number of stems. As with the other parameters, stem volume index (Fig. 4.10) was greater for *A. galpinii* at the ages of 2.5, 4.5 and 6.5 years than for *F. albida*. The difference between the species was statistically significant ($p<0.0001$) in all the years (Appendix 4, Table 5).

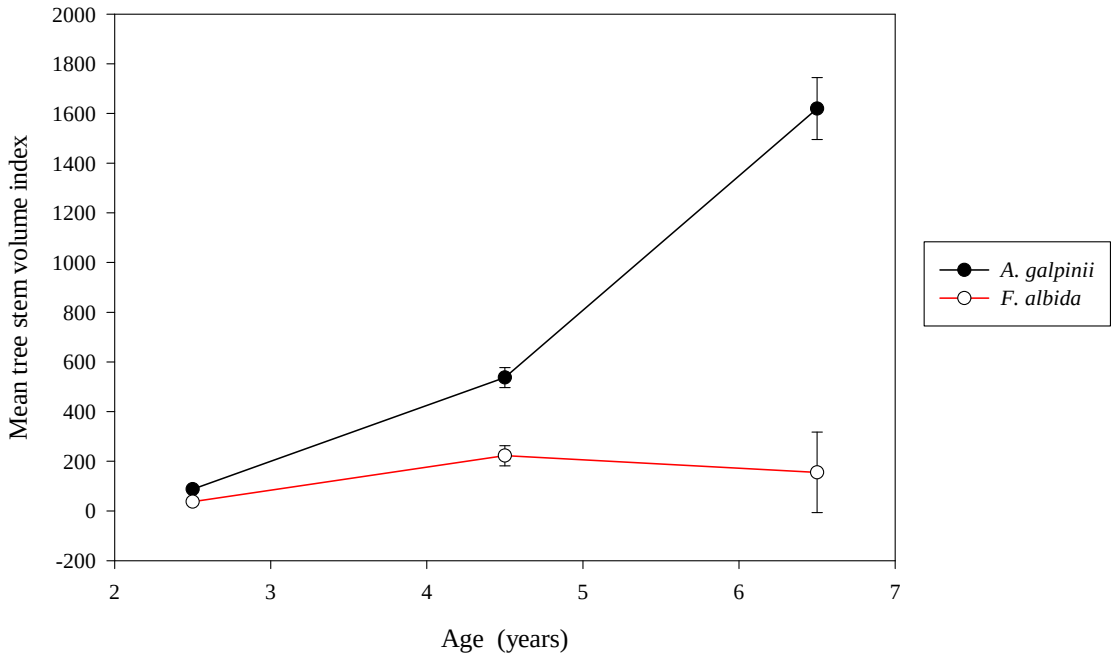


Fig. 4.10 Mean tree stem volume index of indigenous trees

n = 60 except for *F albida* at 6.5 years n = 41

Mean tree stem volume indices of *A. galpinii* and *F. albida* at different plot densities for the period of study are shown in Figures 4.11 and 4.12 respectively.

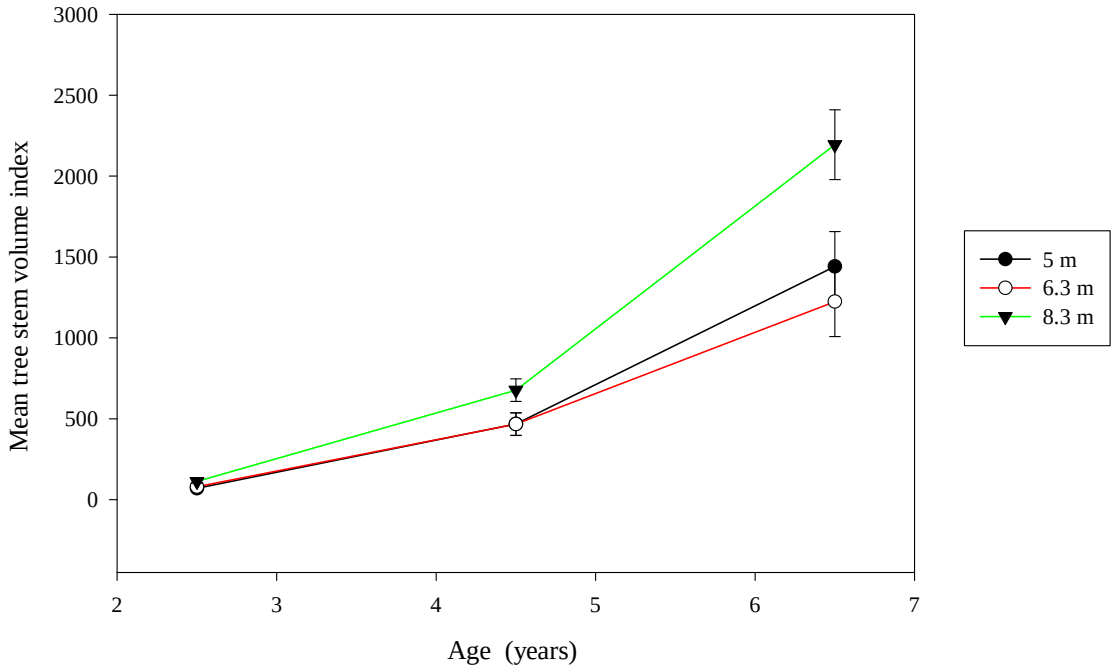


Fig. 4.11 Mean tree stem volume index of A. galpinii *at different spacings*

The mean tree stem volume index of *A. galpinii* (Fig. 4.11) at the age of 2.5 years in the low density plots was greater than those of both medium and high density spacings, while the mean tree stem volume indices of the medium and high density spacings were similar. At the ages of 4.5 and 6.5 years the trend was similar to that of trees aged 2.5 years. The p–values were 0.0565 and 0.0541 respectively, as shown by analysis of variance results in Appendix 4, Table 5.

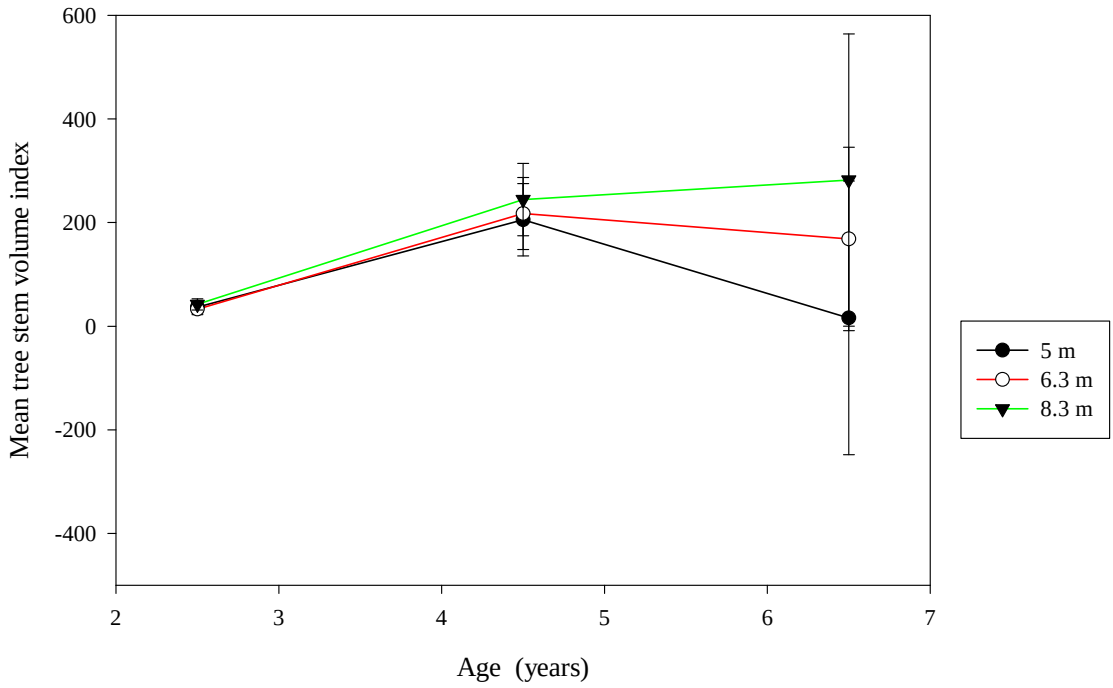


Fig. 4.12 Mean tree stem volume index of F. albida *at different spacings*
n = 20 except at 6.5 years n = 14, 14 and 13 at high, medium and low density respectively

As shown in Figure 4.12 the *F. albida* mean stem volume index was also greatest in low density plots at the ages of 2.5 and 4.5 years, while the lowest means were in the high density spacings. As with other parameters, the mean stem volume index declined due to the high mortality of trees between the ages of 4.5 and 5.5 years. Species x spacing interaction was not significant at all data collections (Appendix 4, Table 4,).

4.1.6 Simple Statistical Correlation Coefficients of Indigenous Trees

Correlation coefficients of parameters are presented in Table 4.1.

Table 4.1 Correlation coefficients for the indigenous tree species

Parameter	*A. galpinii*				*F. albida*			
Cw &	1994 (0.5)	1996 (2.5)	1998 (4.5)	2000 (6.5)	1994 (05)	1996 (2.5)	1998 (4.5)	2000 (6.5)
Dbhno	0.166ns	0.261ns	0.268ns	0.336**	0.244ns	0.140ns	-0.036***	0.651***
Dbh	-	0.145ns	0.671***	0.768***	-	0.613***	0.656***	0.816***
Ht	0.726***	-.0.071ns	0.636***	0.722***	0.764***	-0.044ns	0.643***	0.881***
Svi	-	0.251ns	0.692***	0.785***	-	0.590***	0.610***	0.874***
Dbhno &								
Dbh	-	-0.169ns	-0.163ns	-0.089ns	-	-.203ns	-0.321*	0.214ns
Ht	0.084ns	-0.231ns	-.0156ns	0.264*	0.024ns	0.084ns	-0.289*	0.637***
Svi	-	0.327*	0.485***	0.483***	-	0.370***	0.207ns	0.632***
Dbh &								
Ht	-	0.255*	0.987***	0.707***	-	0.201ns	0.971***	0.841***
Svi	-	0.722***	0.663***	0.661***	-	0.711***	0.804***	0.732***
Ht &								
Svi	-	0.428***	0.649***	0.754***	-	0.203ns	0.825***	0.69***

Cw-crown width; Dbhno- number of diameters at breast height, Dbh-diameter at breast height, Ht-height; Svi-stem volume index. ns=not significant p>0.05; * significant p≤0.05; **significant p≤0.01; ***significant at p≤0.001

The association between crown width and stem number was not significant for *A. galpinii* until the year 2000 at age of 6.5 years (r = 0.336). For *F. albida* there was a significant, but negative, relationship between crown width and stem number in 1998, i.e. 4.5 years from planting (r = -0.036). Six and a half years from planting, regenerated *F. albida* trees showed a strongly significant and positive association between crown width and stem number (r = 0.651).

There were strong positive associations between crown width and height of *A. galpinii* at the ages of 0.5, 4.5 and 6.5 years, but not at the age of 2.5 years, when the non-significant r value was negative (r = - 0.071). A similar result was observed with *F. albida* at the age of 2.5 years (r = -0.044). For *F. albida* there were significant positive associations between crown width and height at six months (r = 0.764), at 4.5 years (r = 0.643) and at 6.5 years (r = 0.874).

For *A. galpinii* the association between crown width and dbh was highly significant at the age of 4.5 years (r = 0.671), with an even more marked correlation at 6.5 years (r = 0.768).

With *A. galpinii* the association between height and dbh was highly positive at the age of 2.5 years (r = 0.255) and this relationship became greater at 4.5 years r = 0.987 and high but lower r-value at 6.5 years was recorded r = 0.707. The relationship between dbh and stem volume index should be highly significant: the values were r = 0.722, 0.663 and 0.661 at the ages of 2.5, 4.5 and 6.5 years respectively. The association between height and stem volume index was highly significant for all data collected (r = 0.428, 0.649 and 0.754 at the ages 2.5, 4.5 and 6.5 years).

With *F. albida* the correlation coefficients for dbh and height were r = 0.971 and r = 0.841 at the ages of 4.5 and 6.5 years respectively, while the r-values for height and stem volume index were 0.825 and 0.69 respectively.

4.2 PERFORMANCE OF EXOTIC TREES

4.2.1 General Observations

The first measurements were taken six months after planting, i.e. in May 1994, and involved survival percentage, crown width and height. The same variables were assessed annually in May until May 2000. The survival of *L. diversifolia* was 87% and that of *L. leucocephala* 97%. In both species these survival rates were maintained throughout the study, although the performance of each species varied under the contrasting rainfall regimes of different years. Such differences between species were also obvious after each complete plant harvest in May 1996, May 1998 and May 2000.

L. leucocephala flowered and produced pods earlier than *L. diversifolia*, in November or December depending on the onset of rain (Appendix 2, Figure 1). *L. diversifolia* mostly accumulated foliage at the beginning of the rainy season and generally flowered in January. Harvesting of pods was mostly confined to the end of the wet season. *L. leucocephala* produced more leaves than *L. diversifolia* in most years. The trend was for a greater mean tree stem

diameter with *L. diversifolia* than for *L. leucocephala* in all years of measurement, except for 1999 when the values were similar.

Appendix 5, Table 1 shows mean values and standard errors for the two species for all parameters over the years of data collection at the three spacings. The first complete plant harvesting was carried out when trees were aged 2.5 years. For all figures relating to Appendix 5, Table 1 the age of trees (line 2 along the X-axis) will add to 6.5 years if addition is started at 2.5 years and the age at harvest are added. Figures show a zigzag pattern of low and high values, which are measurements of coppice growth after the first complete plant harvest at 2.5 years. The coppice shoots that developed were measured at ages 12 (1997) and then at 24 months (1998) when they were harvested. Coppice shoots from the rotation of coppice were again measured at ages of 12 months (1999) and then at 24 months (2000), when harvests for accumulated biomass measurements were conducted.

Throughout the presentation the terms high, medium and low density are applied to stands in order to make comparisons of growth. As indicated in section 3.3, high density plots are spaced at 5 x 5 m, medium density at 6.3 x 5 m, and low density at 8.3 x 5 m.

4.2.2 Crown Width

Mean tree crown width of the two species is shown in Figure 4.13.

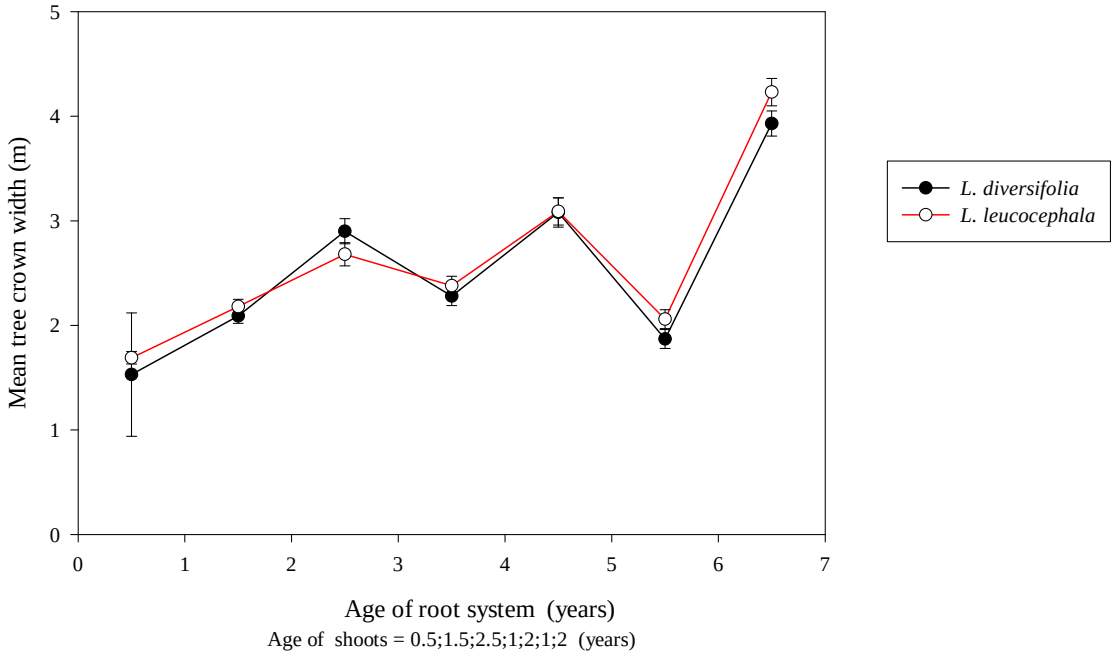


Fig. 4.13 Mean tree crown width of exotic trees

n = 57 for *L diversifolia* and n = 60 for *L. leucocephala*

The figure 4.13 shows both low and high value measurements due to ages of coppice shoots at 12 months from regeneration and 2 years of growth.

When trees were 0.5 and 1.5 years old, *L. leucocephala* had a greater mean crown width than *L. diversifolia.* However, at the age of 2.5 years when measurements were taken before the complete plant harvest, *L. diversifolia* trees exhibited a greater mean tree crown width than *L. leucocephala.* The coppice regeneration data taken at the age of 3.5 years show that *L. leucocephala* had a greater crown width than *L. diversifolia.* The two species had similar crown width at the age 4.5 years. At the ages 5.5 and 6.5 years *L. leucocephala* had a greater mean crown width than *L. diversifolia.*

At the age of 0.5 years the difference between the crown widths of the two species was not significant, but the p-value was 0.0577. Thereafter the two species did not differ statistically significantly in mean tree crown width except at the age of 5.5 years when *L. leucocephala* had a significantly greater mean tree crown width than *L. diversifolia* (Appendix 5, Table 2 : p = 0.0443).

The mean tree crown widths of *L. diversifolia* and *L. leucocephala* at different spacings are presented in Figures 4.14 and 4.15. Mean crown width for all years is shown in Appendix 5, Table 1, Column 5.

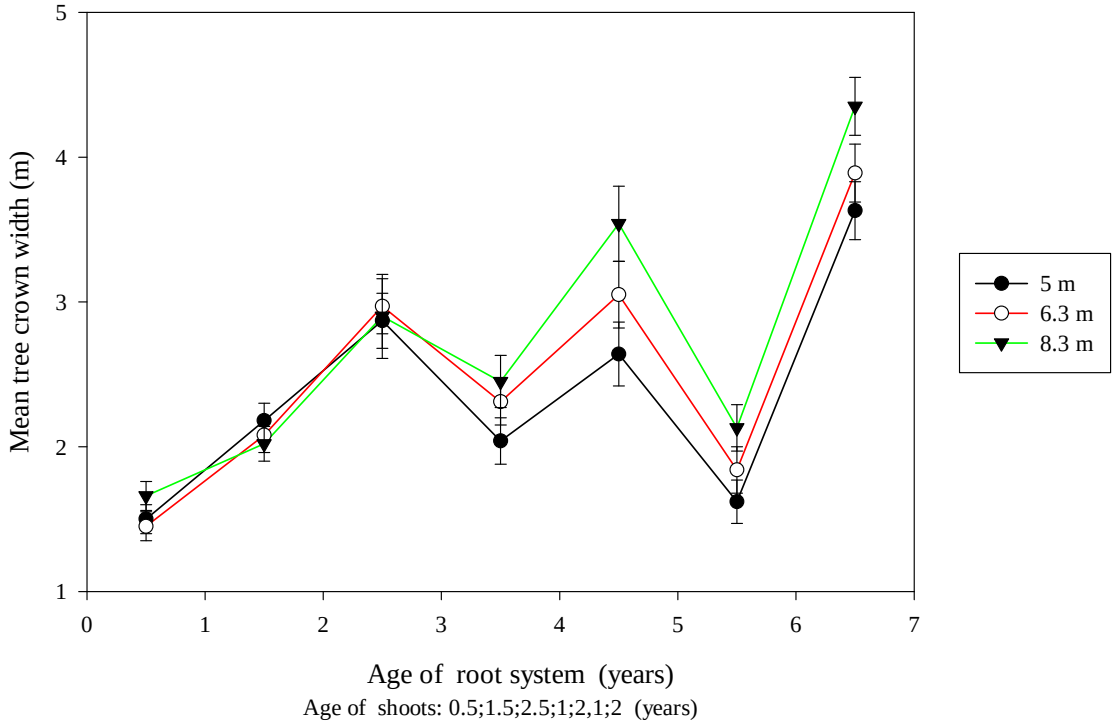


Fig. 4.14 Mean tree crown width of L. diversifolia *at different spacings*

n = 20 except for low density where n =17

Figure 4.14 shows the mean crown width of *L. diversifolia* over the 6.5 years at the different spacings. At the age of 0.5 years and from 3.5 years until the final harvest mean crown width was greatest in low density stands, while the high density plot means were lowest. After the first complete plant harvesting, the mean tree crown width exceeded two metres in all spacings, with

the best growth in diameter at the age of 3.5 years being in the low density plantings. This trend continued in subsequent years with the greatest mean tree crown width in low density plots and the smallest in high density stands at the ages of 4.5, 5.5 and 6.5 years.

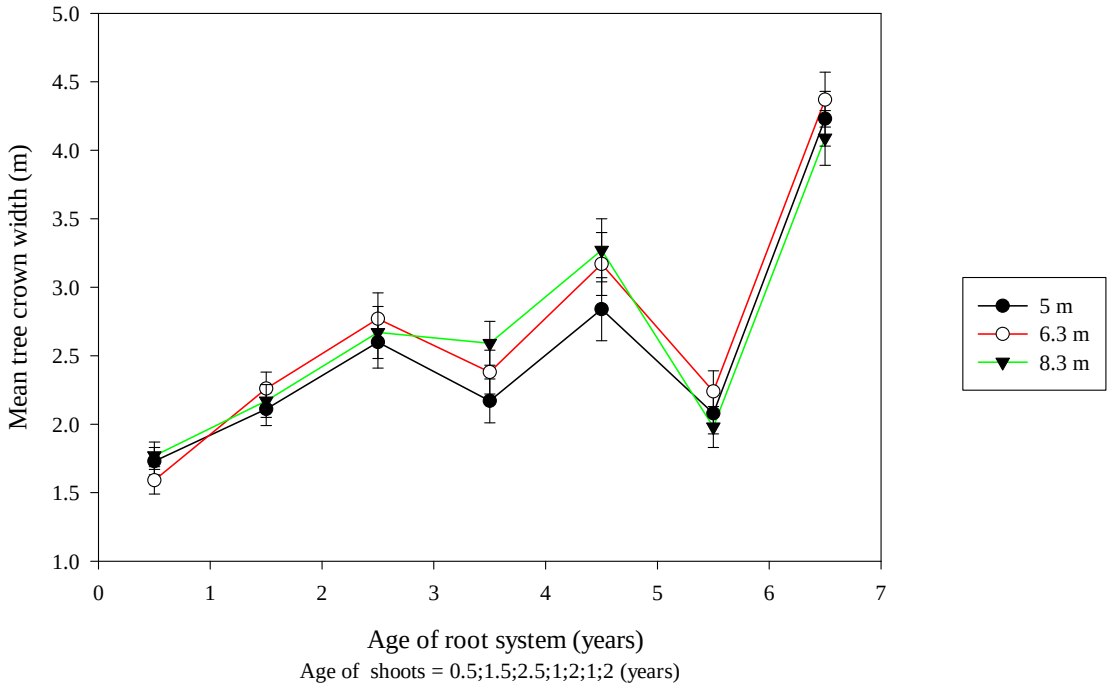


Fig. 4.15 Mean tree crown width of L. leucocephala *at different spacings*

n = 20

Figure 4.15 shows that for *L. leucocephala* mean tree crown width at the age of 0.5 years was greatest in low density stands, while at 1.5 and 2.5 years mean values were greatest in the medium density plots. After the first complete plant harvest, which was carried out at 2.5 years, mean crown width of coppice shoot growth at the ages of 3.5 and 4.5 years was greatest in low density plots. In contrast, at the ages of 5.5 and 6.5 years, following the second complete plant harvest, trees at medium density had the greatest mean crown width, while low density plots had the lowest values.

Analysis of variance (Appendix 5, Table 2) shows that the contrast was significantly different among spacings, $p = 0.0357$ and $p = 0.0396$ at the ages of 3.5 and 4.5 years respectively. The

mean of the low density plots was significantly greater than those of both medium and high density stands.

Analysis of variance (Appendix 5, Table 2) shows that species x spacing interaction was significant at the age of 5.5 years ($p = 0.0353$). For *L. diversifolia* crown width was greatest in low density plots while the mean tree crown width of *L. leucocephala* was greatest in the medium density plots. At the final harvest, 6.5 years after planting, species x spacing interaction was not significant, but the p-value was low ($p = 0.0738$). The mean tree crown width for *L. diversifolia* was greatest in the low density stands and high density plots had the lowest value. On the other hand, with *L. leucocephala* the mean crown width was greatest in the medium density plots with the smallest values being recorded in low density stands.

4.2.3 Height

Comparison of mean tree heights of the two species at different stages of measurement is shown in Figure 4.16. Mean tree heights were similar between the two species in most years of data collection except at the age of 5.5 years (in 1999), when *L. leucocephala* had a greater mean height than *L. diversifolia*. The difference between the means of the two species was statistically significant ($p = 0.0002$) at that measurement (Appendix 5, Table 3).

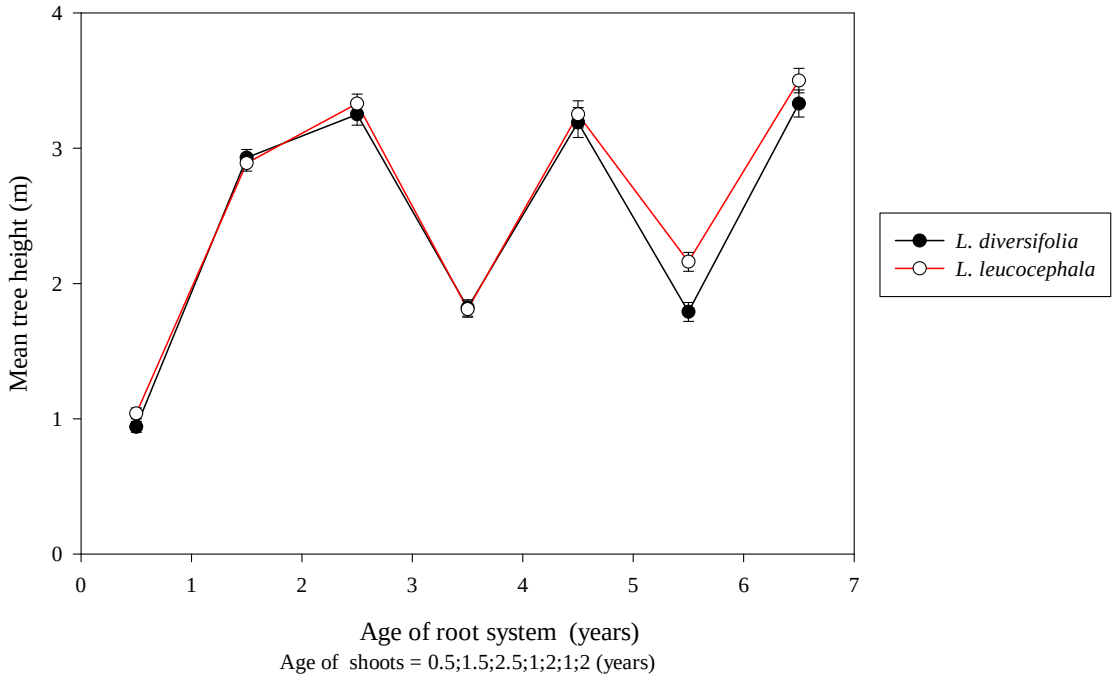


Fig. 4.16 Mean tree height of exotic trees

n = 57 for *L. diversifolia* n = 60 for *L. leucocephala*

Mean tree heights of *L. diversifolia* and *L. leucocephala* at contrasting spacings are shown in Figures 4.17 and 4.18 respectively.

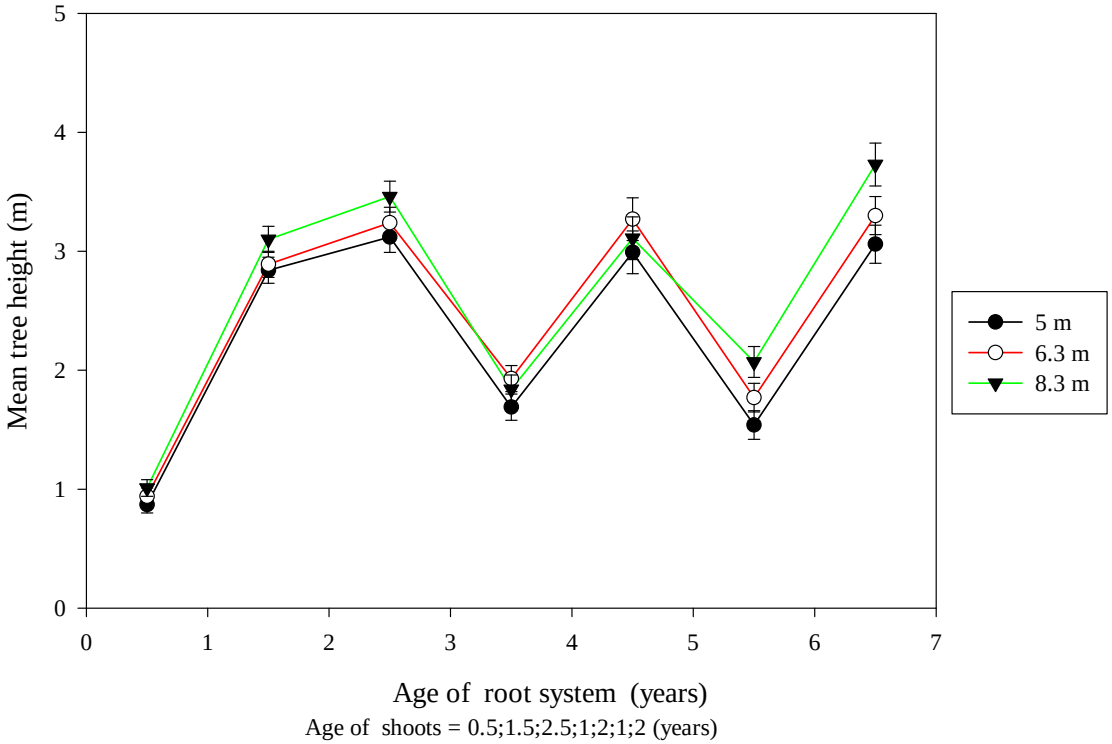


Fig. 4.17 Mean tree height of L. diversifolia *at different spacings*

n = 20 except for low density where n = 17

The *L. diversifolia* (Fig. 4.17) mean tree height was greatest in low density spacings in the first 2.5 years of plant growth. However, after the first complete plant harvest, trees at medium density spacing had a greater mean height than those in low density plots. High density plots had the lowest height growth values throughout the study period.

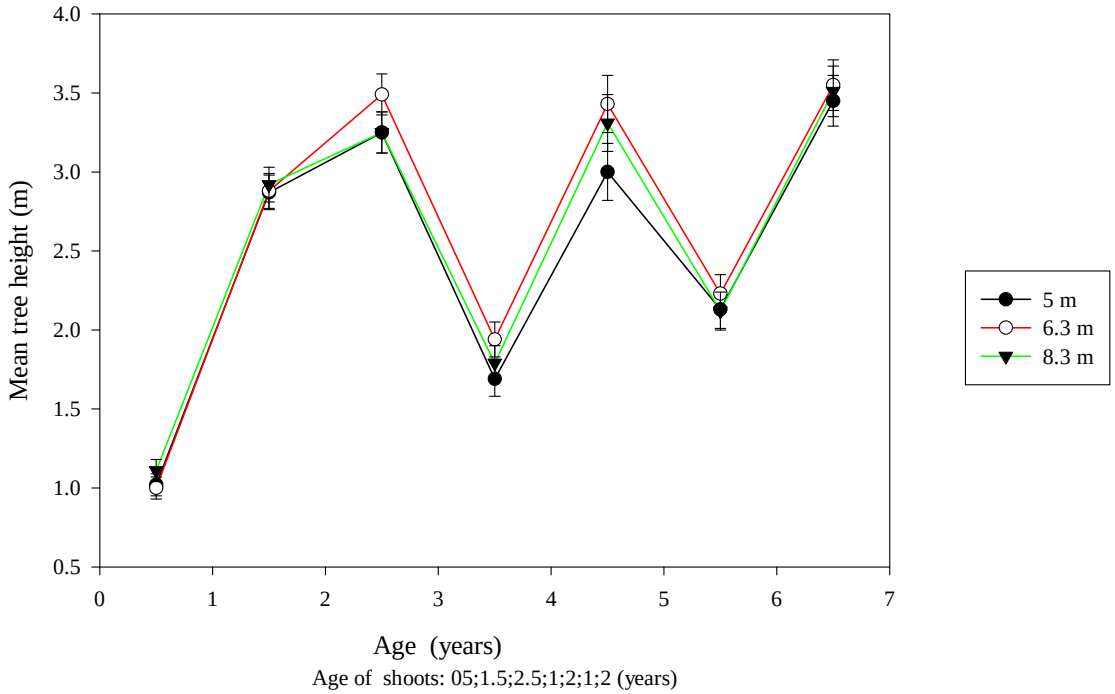


Fig. 4.18 Mean tree height of L. leucocephala *at different spacings*

n = 20

The mean heights of *L. leucocephala* at different spacings over the study period are shown in Figure 4.18. From the age of 2.5 years until the final data collection, when trees were aged 6.5 years, mean tree height was greatest in the medium density stands, while high density plots had the smallest means. Mean tree height variations were not significant among plots of different spacing. However, p-values were low at the ages of 3.5 and 6.5 years ($p = 0.0718$ and $p = 0.0656$ respectively, Appendix 5, Table 3).

Species x spacing interaction was not significant except at the age of 5.5 years ($p = 0.0496$) (Appendix 5, Table 3). *L. diversifolia* mean tree heights were greatest in low density plots, while values for *L. leucocephala* were greatest in the medium density stands at most measurements.

4.2.4 Stem Diameter at 50 cm

Figure 4.19 compares the two species with respect to the growth of mean tree stem diameter at a height of 50 cm.

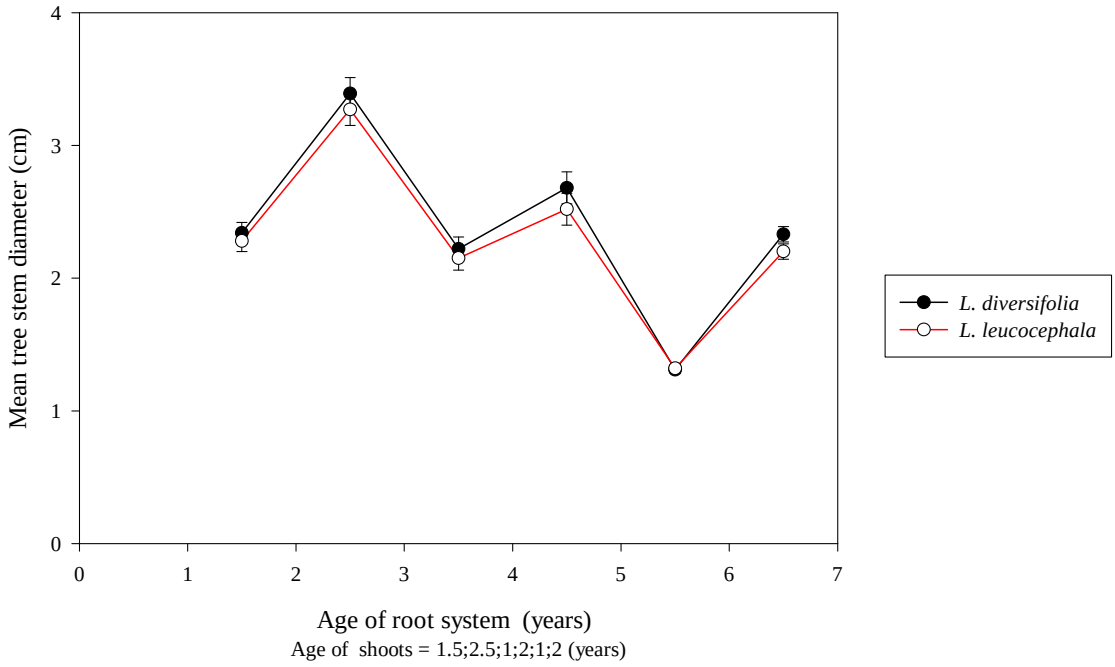


Fig. 4.19 Mean tree stem diameter of exotic trees

n = 57 for *L diversifolia* n = 60 for *L. leucocephala*

L. diversifolia exhibited a greater mean stem diameter than *L. leucocephala* throughout the study, except at the age of 5.5 years when the means were identical. The differences between the species were not statistically significant (Appendix 5, Table 4). For the species coppice shoot stem diameter growth at the end of the first season was almost the same as that of plants aged 1.5 years. Coppice shoot mean stem diameter 12 months after the second complete plant harvest was much smaller than that of growth after the first complete plant harvest.

Mean tree stem diameter at different plot densities for *L. diversifolia* and *L. leucocephala* is shown in Figures 4.20 and 4.21.

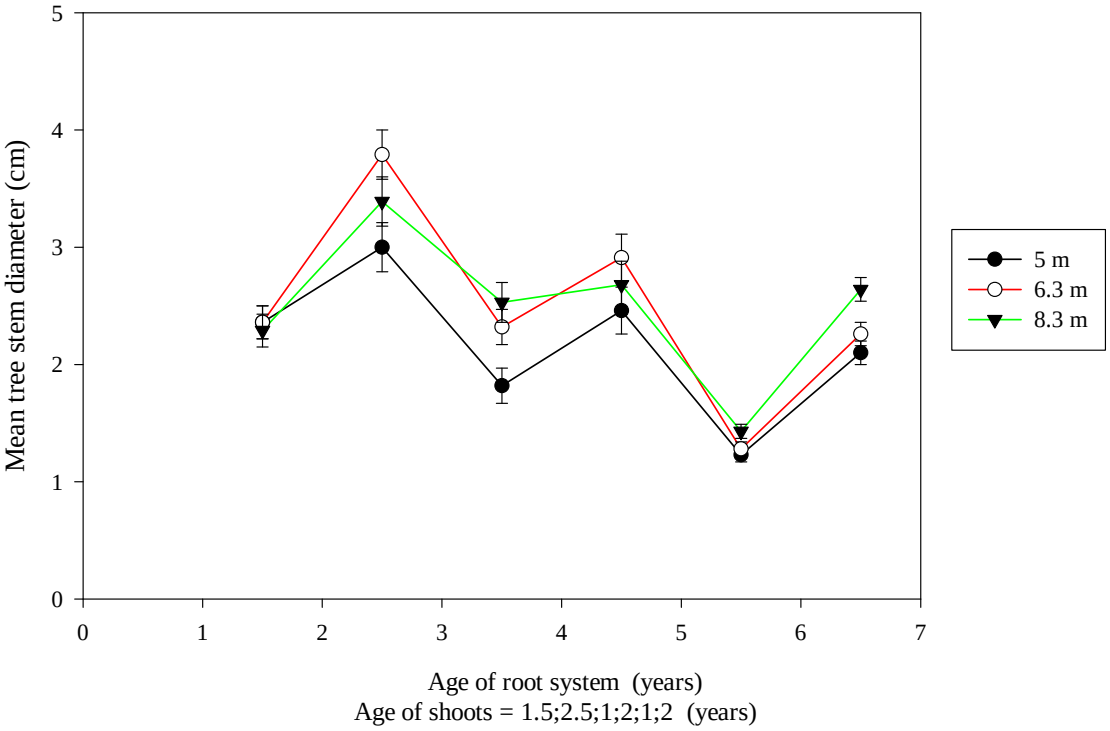


Fig. 4.20 Mean tree stem diameter of L. diversifolia *at different spacings*

n = 20 except at low density plots n = 17

At the ages of 1.5, 2.5 and 4.5 years the mean tree stem diameter of *L. diversifolia* was greatest in medium density stands, with the high density plots having the lowest mean values throughout the study (Fig. 4 20). For the other three years of data collection, at the ages of 3.5, 5.5 and 6.5 years, mean stem diameter was greatest in the low density plots and with the lowest mean values recorded in high density stands.

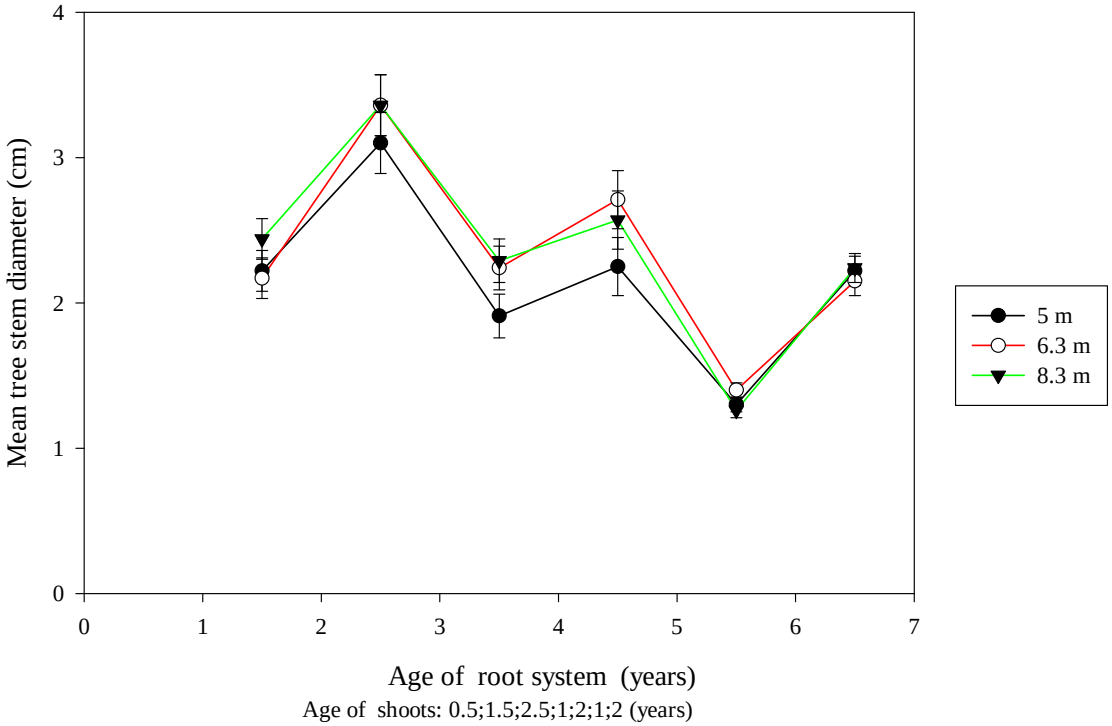


Fig. 4.21 Mean tree stem diameter of L. leucocephala *at different spacings*

n = 20

Figure 4.21 shows stem diameter development for *L. leucocephala*. In the first three years of growth mean tree stem diameter was greatest in low density spacings. However, at the ages of 4.5 and 5.5 years the mean was greatest in the medium density plots, with trees in high density spacings having the smallest mean diameter except at final measurement at the age of 6.5 years.

Analysis of variance (Appendix 5, Table 4) shows that the differences in mean stem diameter of stands were statistically significant at the ages of 2.5, 3.5 and 6.5 years ($p = 0.0444$, 0.0042 and 0.0142 respectively). Means of trees at low density were significantly greater than those of trees in the high density stands.

Species x spacing interaction was significantly different at the ages of 5.5 and 6.5 years ($p = 0.0182$ and $p = 0.0371$ respectively) (Appendix 5, Table 4). *L. diversifolia* trees at low density

had the greatest mean stem diameter, while *L. leucocephala* trees in medium density plots had the highest value.

4.2.5 Shoot Numbers

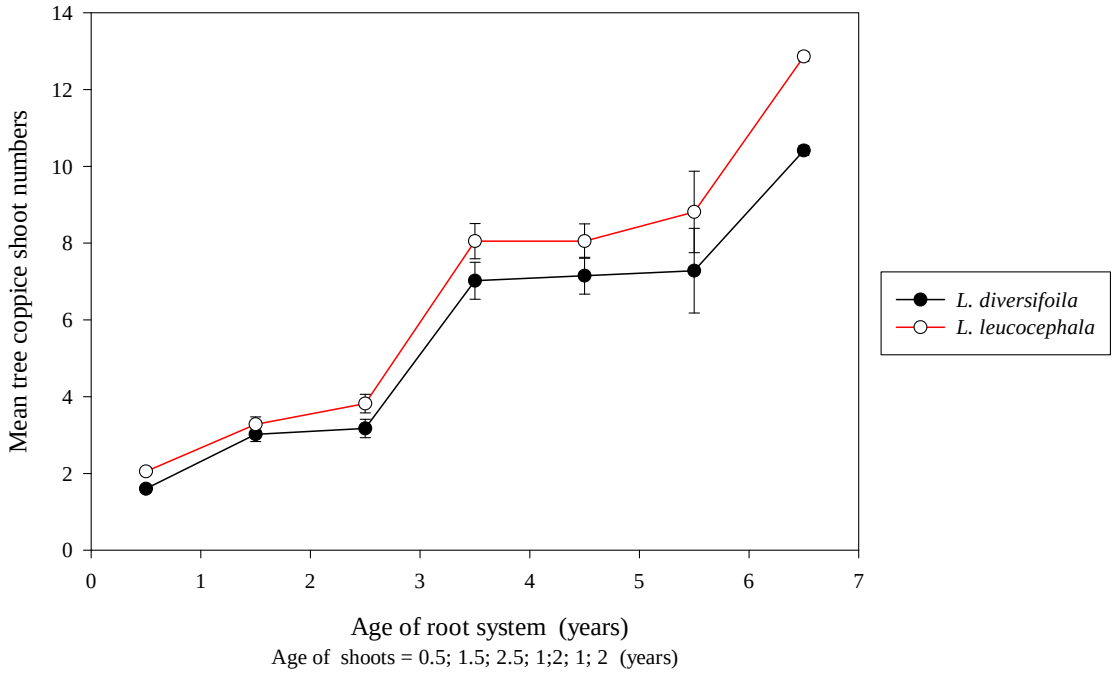


Fig. 4.22 Mean tree coppice shoot numbers of exotic trees

N = 57 for *L. diversifolia;* n = 60 for *L. leucocephala*

Coppice shoot numbers of *L. diversifolia* and *L. leucocephala*, both before and after complete plant harvesting, are presented in Figure 4.22. Throughout the study coppice shoot numbers were greater in *L. leucocephala* compared to *L. diversifolia*.

Mean tree stem number was significantly different between the two species at the age of 0.5 years ($p = 0.0003$). Appendix 5, Table 5 shows analysis of variance. At 2.5 and 3.5 years the difference between the species was pronounced with p-values of 0.0858 and 0.0692 respectively. Whereas at 4.5 and 5.5 years the difference between species was not considerable, at the final harvest, when the trees were aged 6.5 years, the difference was statistically significant ($p =$

0.0045). At that stage the mean number of coppice shoots was 12.86 ± 0.12 for *L. leucocephala* compared to 10.41 ± 0.63 for *L. diversifolia*.

The mean number of coppice shoots of *L. diversifolia* at different spacings is shown in Figure 4.23.

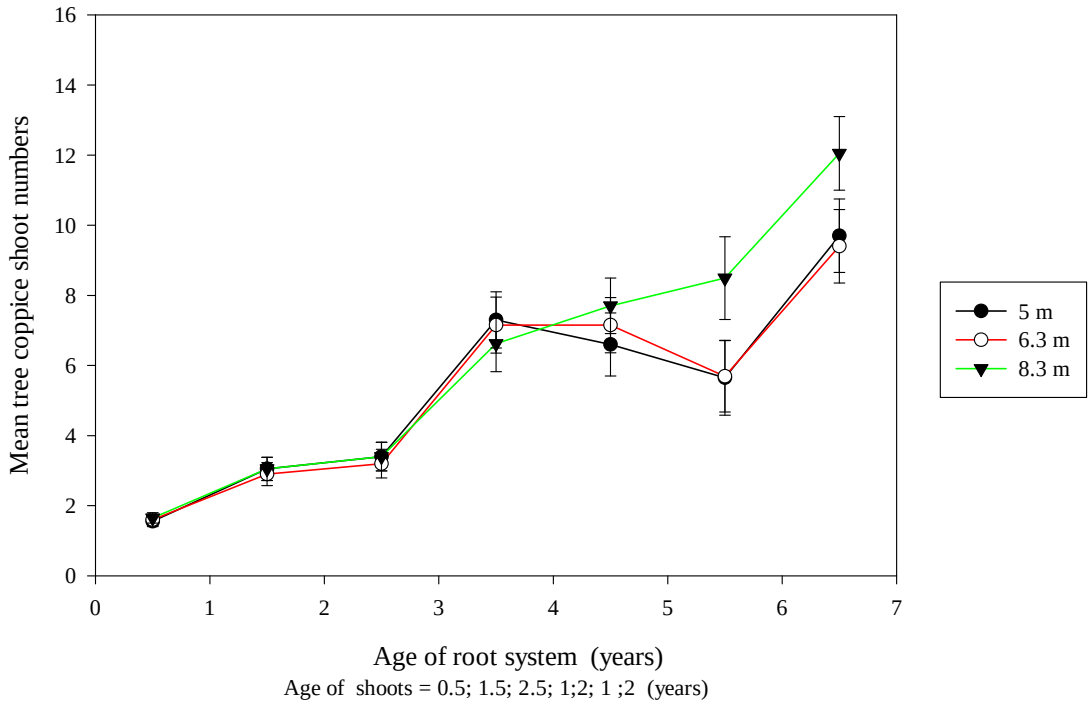


Fig. 4.23 Mean tree coppice shoot numbers of L. diversifolia *at different spacings*

n = 20 except at low density stands where n = 17

After the first complete plant harvest the number of shoots increased in all spacings, leading to an average of seven shoots per tree. Following the second plant harvest 4.5 years after planting, coppice shoot development was greatest in the low density stands and lowest in high density plots. At the ages of 5.5 and 6.5 years mean coppice shoot number was significantly more in low density plots than in medium and high density plots, while the number of shoots in medium and high density stands was comparable (Appendix 5, Table 1).

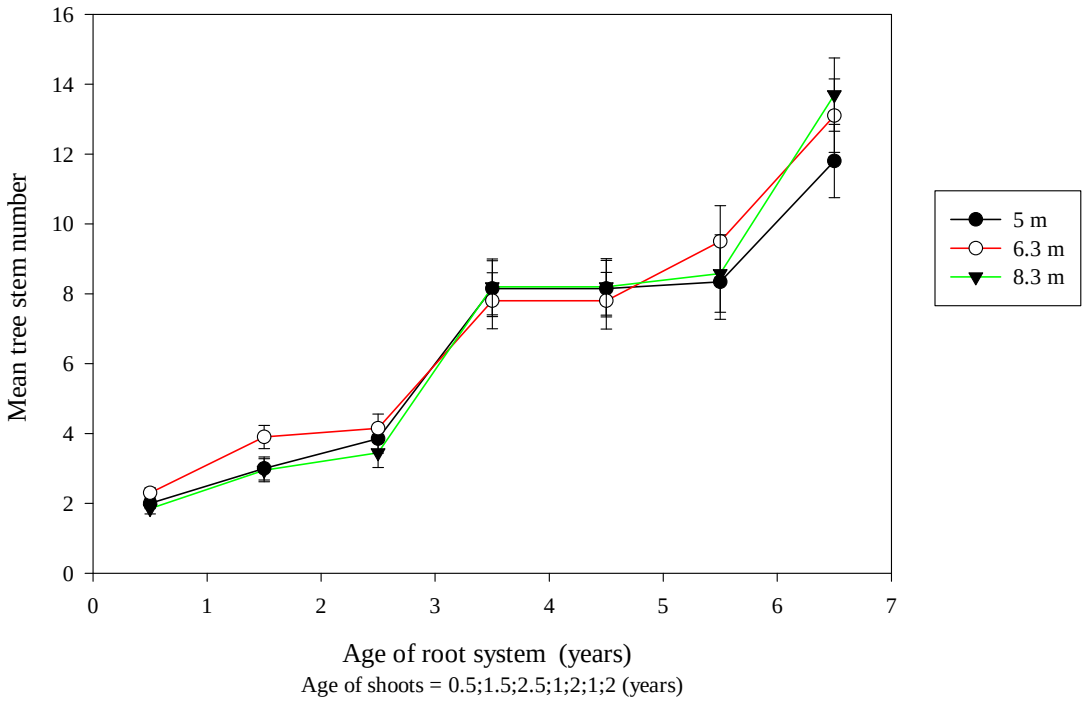


Fig. 4.24 Mean tree coppice shoot number of L. leucocephala *at different spacings*

n = 20

With *L. leucocephala* (Figure 4.24) the planting density at which the highest number of shoots was recorded varied during the study. At 0.5, 1.5, 2.5 and 5.5 years the highest mean shoot numbers were in the medium density plots. However, at the final measurement at the age of 6.5 years coppice shoots were most numerous in the low density stands.

There were no significant differences in coppice shoot numbers among the three planting densities (Appendix 5, Table 5). However, the number of coppice shoots was greater in low density plots, especially for *L. diversifolia,* while with *L. leucocephala* medium and low density mean coppice shoot numbers were similar, but greater than those of high density plots.

Species x spacing interaction was significant at the age of 5.5 years, as shown in the analysis of variance results in Appendix 5, Table 5 ($p = 0.0063$). With *L. diversifolia* the mean number of

coppice shoots was greatest in the low density stands, while for *L. leucocephala* the medium density plots had the highest number of shoots (Appendix 5, Table 1).

4.2.6 Stem Volume Index

Stem volume index is an estimate of biomass production, calculated through mean tree stem diameter squared, multiplied by mean tree height and by the number of coppice shoots or stems (mean std^2 x ht x stno).

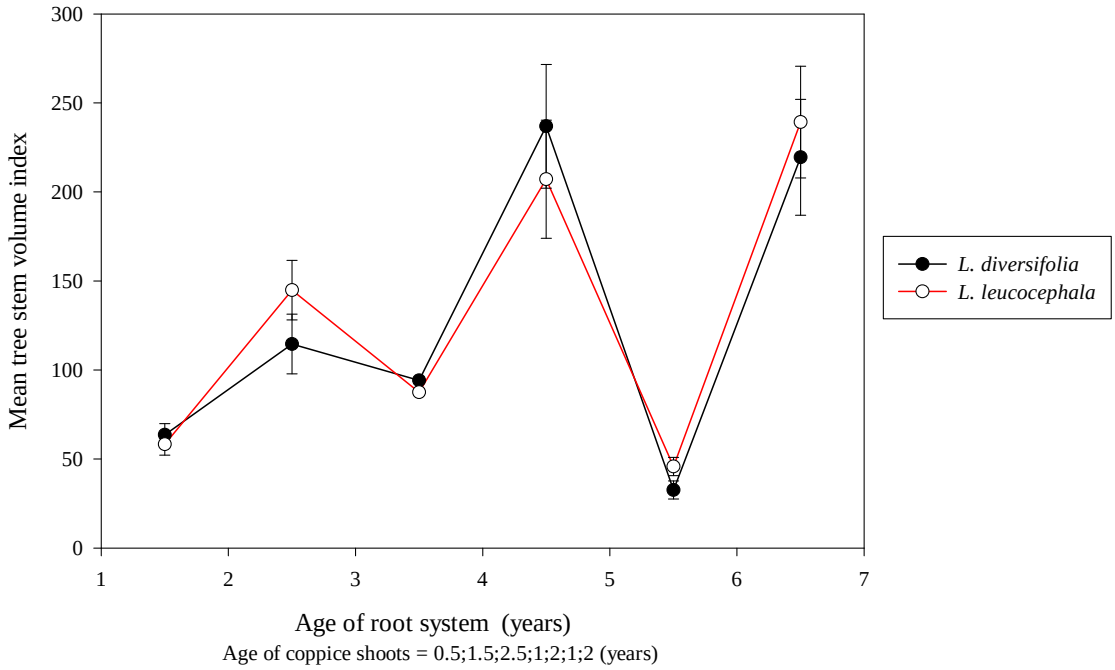


Fig. 4.25 Mean tree stem volume index of exotic trees

n = 57 for *L. diversifolia;* n = 60 for *L. leucocephala*

Figure 4.25 shows the mean tree stem volume indices of the two exotic species at various ages. *L. diversifolia* had a greater mean tree stem volume index than *L. leucocephala* at the ages of 1.5, 3.5 and 4.5 years, while at the ages of 2.5, 5.5 and 6.5 years *L leucocephala* had greater mean stem volume indices than *L. diversifolia*. The contrast between species was not statistically significant throughout the study (Appendix 5, Table 6).

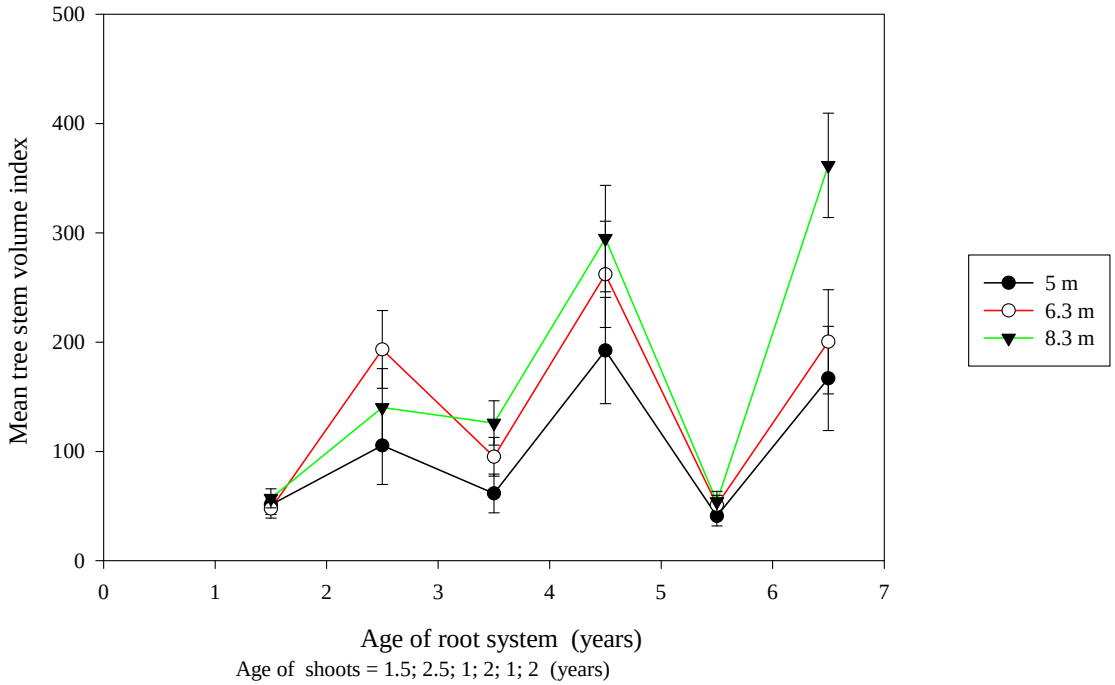


Fig. 4.26 Mean tree stem volume index of L. diversifolia *at different spacings*

n = 20 except for low density plantings where n = 17

The mean tree stem volume index of *L. diversifolia* (Fig. 4.26) was greatest in the low density plots, except at the age of 2.5 years when the value was highest in the medium density spacings.

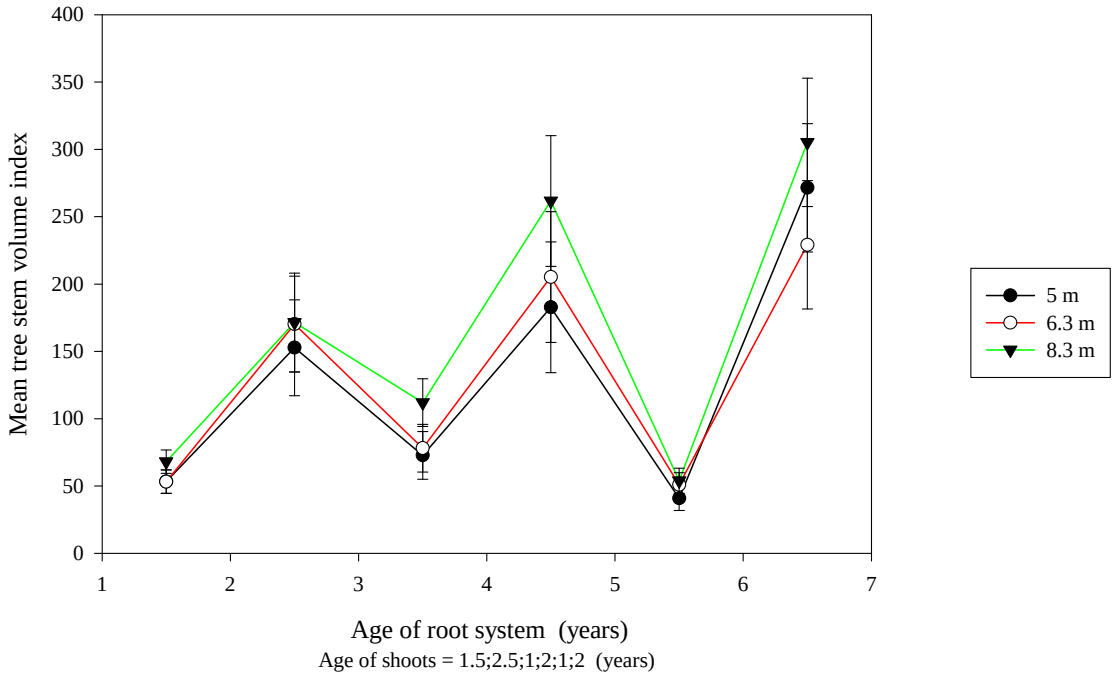


Fig. 4.27 Mean tree stem volume index of L. leucocephala *at different spacings*

Throughout the study the growth in mean stem volume index of *L. leucocephala* was greatest in the low density plots, with the lowest values being recorded in high density stands, except at 6.5 years when medium density stands had the lowest stem volume index value (Fig. 4.27).

Analysis of variance results are presented in Appendix 5, Table 6. There were significant differences in stem volume index among the three planting densities at the ages of 3.5 and 6.5 years ($p = 0.0468$ and $p = 0.0310$ respectively).

Species x spacing interaction was not statistically significant throughout the study, even though at the age of 3.5 years *L. diversifolia* had the greatest mean stem volume index in medium density spacings, while *L. leucocephala* had the greatest mean in the low density plots throughout the study.

4.2.7 Agroforestry Production per Tree

4.2.7.1 General

Complete plant harvesting was carried out in 1996, 1998 and 2000, i.e. 2.5, 4.5 and 6.5 years after planting (methodology section 3.5.4.2). The mass of harvested plant material of leaves and pods was for the growing seasons of September to May 1995/1996, 1997/1998 and 1999/2000 (wet seasons). For wood dry matter the mass was for 2.5 years in 1996 and 2 years for both the 1998 and 2000 harvests. Mean yields per tree for *L. diversifolia* and *L. leucocephala* are presented in Table 4.2. The leaf and pod mass was oven-dried, while the wood mass was air-dried.

Table 4.2 Mean tree biomass yields of L. diversifolia *and* L. leucocephala *(kg)*

Year (Age years)	Species	Spacing	N	Leaf	Pod	Wood	Total
1996 (2.5)	*L. diversifolia*	5	20	2.24 ± 0.40a	3.35 ± 0.45a	8.99 ± 1.17a	14.60 ± 1.911a
		6.3	20	1.90 ± 0.39a	2.93 ± 0.45a	7.05 ± 1.17a	11.88 ± 1.911a
		8.3	17	1.81 ± 0.39a	2.99 ± 0.45a	7.12 ± 1.17a	11.92 ± 1.911a
	Mean		57	1.89 ± 0.28B	2.91 ± 0.35B	7.37 ± 0.88B	12.80 ± 1.10B
	L. leucocephala	5	20	3.97 ± 0.39a	4.37 ± 0.45a	9.28 ± 1.17a	17.63 ± 1.911a
		6.3	20	3.97 ± 0.39a	5.04 ± 0.45a	12.29 ± 1.17a	21.31 ± 1.11a
		8.3	20	3.58 ± 0.39a	3.93 ± 0.45a	8.29 ± 1.17a	15.80 ± 1.911a
	Mean		60	3.75 ± 0.28A	4.32 ± 0.33A	9.80 ± 0.88A	18.24 ± 1.10A
1998 (4.5)	*L. diversifolia*	5	20	0.49 ± 0.11a	0.23 ± 0.30a	6.25 ± 1.38a	6.94 ± 1.6299b
		6.3	20	0.34 ± 0.11a	0.67 ± 0.31a	6.67 ± 1.38a	7.54 ± 1.629ba
		8.3	17	0.49 ± 0.11a	1.27 ± 0.28a	11.68 ± 1.38a	11.66 ± 1.629a
	Mean		57	0.47 ± 0.08A	0.72 ± 0.17B	8.45 ± 1.09A	8.71 ± 0.940A
	L. lecucocephala	5	20	0.43 ± 0.11a	1.17 ± 0.29a	7.27 ± 1.38a	8.75 ± 1.629a
		6.3	20	0.51± 0.11a	1.54± 0.28a	7.99± 1.38a	10.05 ± 1.63ba
		8.3	20	0.64 ± 0.11a	1.35 ± 0.29a	8.36 ± 1.38a	10.28 ± 1.629a
	Mean		60	0.48 ± 0.07A	1.44 ± 0.22A	7.44 ± 1.04A	9.69 ± 0.094A
2000 (6.5)	*L. diversifolia*	5	20	2.26 ± 0.41a	1.29 ± 0.58b	5.07 ± 1.39b	8.54 ± 2.198b
		6.3	20	2.23 ± 0.41a	1.04 ± 0.58b	6.15 ± 1.39b	9.43 ± 2.198ba
		8.3	17	3.05 ± 0.41a	3.58 ± 0.58a	10.85 ± 1.39a	17.64 ± 2.198a
	Mean		57	2.38 ± 0.34A	1.79 ± 0.46B	6.68 ± 3.84A	11.87 ± 1.27B
	L. lecucocephala	5	20	2.77 ± 0.41a	4.34 ± 0.60b	8.95 ± 1.39b	15.911 ± 2.20b
		6.3	20	3.07 ± 0.41a	4.27 ± 0.58b	9.98 ± 1.39b	17.3 1± 2.20ba
		8.3	20	2.86 ± 0.41a	6.54 ± 0.58a	10.95 ± 1.39a	20.35 ± 2.198a
	Mean		60	2.76 ± 0.32A	4.43 ± 0.44A	9.46 ± 1.00A	17.86 ± 1.27A

Means in a column followed by different letters abc are significantly different among spacings within species within year of assessment $p \leq 0.05$

4.2.7.2 Mean Tree Leaf Mass

At the harvest of trees aged 2.5 and 6.5 years the mean leaf mass of *L. leucocephala* was greater than that of *L. diversifolia*, while at the harvest of trees aged 4.5 years leaf yield was similar between species (Table 4.2). Analysis of variance (Appendix 5, Table 7) shows that the difference in mean leaf mass between the two species was highly significant ($p<0.0001$) at the harvest when trees were aged 2.5 years. At the ages of 4.5 and 6.5 years there were no significant differences of leaf mass between the two species.

As shown in the analysis of variance results (Appendix 5, Table 7), mean leaf mass did not vary significantly among planting densities. There was little consistency in the pattern of performance in relation to spacing. Species x spacing interaction was not significant throughout the study.

4.2.7.3 Mean Tree Pod Mass

Pod mass is shown in Table 4.2, Column 6. The results demonstrate greater production of *L. leucocephala* compared to *L. diversifolia* throughout the study. Analysis of variance (Appendix 5, Table 8) shows that the differences between the species were highly significant ($p = 0.0004$, $p = 0.0098$ and $p<0.0001$ at the ages of 2.5, 4.5 and 6.5 years respectively).

Pod mass per tree of *L. diversifolia* was significantly more in the final harvest at the age of 6.5 years in the low density stands than in the medium and the high density plantings. The same significant differences occurred within *L. leucocephala*.

Analysis of variance results (Appendix 5, Table 8) show that within species and ages there were no other significant differences in pod yields.

4.2.7.4 Mean Tree Wood Mass

The mean wood mass per tree of both species is shown in Table 4.2, Column 7. At the ages of 2.5 and 6.5 years *L. diversifolia* had a significantly lower mean wood mass than *L. leucocephala* ($p = 0.0213$ and 0.0241 respectively) (Appendix 5, Table 9). In contrast, at the plant harvest of 1998, 4.5 years after planting, *L. diversifolia* had a non-significant bigger mean wood mass than *L. leucocephala.*

At the harvests of trees aged 4.5 and 6.5 years, the mean wood mass was greatest in low density plots for both species (Table 4.6, Column 7). Differences in yield among contrasting spacings were statistically significant ($p = 0.0454$ and 0.0179 respectively) (Appendix 5, Table 9). The

difference between mean wood mass of trees at medium density and those of high density plots was not statistically significant in either year.

Species x spacing interaction was not significant at any of the harvests (Appendix 5, Table 9).

4.2.7.5 Mean Tree Total Biomass

Total biomass yields of the two species at all stages are shown in Table 4.2, Column 8. *L. leucocephala* had a greater mean total biomass than *L. diversifolia* throughout the study. The mean biomass values of trees aged 4.5 years were 8.71 ± 0.94 kg for *L. diversifolia* and 9.69 ± 0.94 kg for *L. leucocephala*. At the final harvest, 6.5 years after planting, the mean biomass values were 11.87 ± 1.27 and 17.86 ± 1.27 kg for *L. diversifolia* and *L. leucocephala* respectively.

The difference between the mean masses of the two species at the age of 2.5 years was statistically significant ($p = 0.0013$). The total biomass was 12.80 ± 1.103 and 18.24 ± 1.103 kg for *L diversifolia* and *L. leucocephala* respectively, while in the harvest of trees aged 6.5 years yields were 11.87 ± 1.269 and 17.86 ± 1.269 kg respectively; the difference between species was not significant, but the p-value was $p = 0.0628$, (Appendix 5, Table 10).

The mean biomass was significantly different among the spacings at the harvests of trees aged 4.5 and 6.5 years ($p = 0.0341$ and $p = 0.0302$ respectively). Trees in low density plots had a greater mean mass than those at medium and high density and those in medium density spacings had greater means than those in high density plots in both years. At all stages of harvest, species x spacing interaction was not significantly different.

4.2.8 Agroforestry Production per Hectare

4.2.8.1 General

As is to be expected from mean yield per tree, the mean yield per hectare of *L. leucocephala* at all harvests was greater than that of *L. diversifolia* (Table 4.3). Observations are made with regard to the effect of spacing. The number of trees per hectare is as given in the methodology section 3.3: high density plots had 400 trees ha^{-1} medium density 317 trees ha^{-1}, and low density 241 trees ha^{-1}.

Table 4.3 Biomass production of L. diversifolia *and* L. leucocephala *(MT ha^{-1})*

Year (Age yrs)	Species	Spacing	Leaf	Pod	Wood	Total
1996 (2.5)	*L. diversifolia*	5	0.902 ± 0.142a	1.342 ± 0.161a	3.597 ± 0.415a	5.84 ± 0.685a
		6.3	0.602 ± 0.142b	0.927 ± 0.161a	2.236 ± 0.414a	3.77 ± 0.685a
		8.3	0.438 ± 0.142c	0.720 ± 0.161b	1.715 ± 0.415b	2.87 ± 0.685b
	Mean		0.647 ± 0.082B	0.996 ± 0.093	2.516 ± 0.239	4.16 ± 0.395
	L. leucocephala	5	1.589 ± 0.142a	1.748 ± 0.161a	3.714 ± 0.415a	7.05 ± 0.685a
		6.3	1.260 ± 0.142b	1.597 ± 0.161a	3.897 ± 0.415a	6.75 ± 0.685a
		8.3	0.862 ± 0.142c	0.948 ± 0.161b	1.999 ± 0.415b	3.81 ± 0.685b
	Mean		1.237 ± 0.082A	1.431 ± 0.093	3.203 ± 0.239	5.87 ± 0.395
1998 (4.5)	*L. diversifolia*	5	0.197 ± 0.038a	0.081 ± 0.079a	2.498 ± 0.446a	2.78 ± 0.506a
		6.3	0.107 ± 0.038a	0.168 ± 0.079a	2.115 ± 0.446a	2.39 ± 0.506a
		8.3	0.113 ± 0.038a	0.301 ± 0.079a	2.395 ± 0.446a	2.81 ± 0.506a
	Mean		0.139 ± 0.022	0.184 ± 0.045	2.336 ± 0.258	2.66 ± 0.292
	L. leucocephala	5	0.174 ± 0.038a	0.420 ± 0.079a	2.907 ± 0.446a	3.50 ± 0.506a
		6.3	0.163 ± 0.038a	0.489 ± 0.079a	2.534 ± 0.446a	3.19 ± 0.506a
		8.3	0.153 ± 0.038a	0.309 ± 0.079a	2.015 ± 0.446a	2.48 ± 0.506a
	Mean		0.163 ± 0.022	0.406 ± 0.045	2.485 ± 0.258	3.05 ± 0.292
2000 (6.5)	*L. diversifolia*	5	0.904 ± 0.134a	0.487 ± 0.176b	2.027 ± 0.433a	3.42 ± 0.685a
		6.3	0.710 ± 0.134a	0.330 ± 0.176b	1.951 ± 0.433a	2.99 ± 0.685a
		8.3	0.741 ± 0.134a	0.865 ± 0.176a	2.644 ± 0.433a	4.25 ± 0.685a
	Mean		0.785 ± 0.077	0.561 ± 0.102	2.207 ± 0.25	3.55± 0.395
	L. leucocephala	5	1.110 ± 0.134a	1.675 ± 0.176a	3.579 ± 0.433a	6.36 ± 0.685a
		6.3	0.973 ± 0.134a	1.352 ± 0.176a	3.162 ± 0.433a	5.49 ± 0.685a
		8.3	0.690 ± 0.134a	1.577 ± 0.176a	2.638 ± 0.433a	4.91 ± 0.685a
	Mean		0.924 ± 0.077	1.535 ± 0.101	3.127 ± 0.250	5.58 ± 0.395

Means in a column followed by different letters abc are significantly different among spacings within species within year of assessment $p \leq 0.05$

4.2.8.2 Leaf Mass per Hectare

For both species at all harvests mean leaf mass per hectare was greatest in high density plantings Analysis of variance results are shown in Appendix 5, Table 11. Leaf mass per hectare was significantly different among planting densities at the harvest of trees aged 2.5 years ($p = 0.0003$), while at the harvest of trees aged 6.5 years the p-value was $p = 0.0980$. Species x spacing interactions were not significant at any of the harvests. At 2.5 years the range was from 0.902, 0.602 and 0.438 tonnes ha^{-1} for *L. diversifolia* and 1.589, 1.260 and 0.862 for *L. leucocephala* in high, medium and low density respectively.

4.2.8.3 Pod Mass per Hectare

There were significant differences between species in pods yields per hectare at all harvest. Species x spacing interaction was not significant at any of the harvests, but the p-value was 0.0641 for the data collected at the age of 4.5 years (Appendix 5, Table 12).

Pod mass of *L. leucocephala* was markedly more than that of *L. diversifolia* and for both species varied considerably between harvests, i.e. 1.431 vs. 0.996 tonnes ha^{-1} at the age of 2.5 years, 0.406 vs. 0.184 tonnes ha^{-1} at 4.5 years and 1.535 vs. 0.561 tonnes ha^{-1} at 6.5 years (Table 4.3 Column 5).

At the age of 2.5 years pod mass of both species increased with an increase in stand density, with the yields in the high density stands being significantly more than in the medium and low density stands. At the harvests of trees aged 4.5 and 6.5 years, there were no clear trends in the effect of stand density on yields of either species (Table 4.3, Column 5).

4.2.8.4 Wood Mass per Hectare

At the harvest of trees aged 2.5 years the wood mass for both *L. diversifolia* and *L. leucocephala* was significantly more in high and medium density plots than in low density plots (Table 4.3, Column 6). Wood yields per hectare obtained from harvests of 4.5 and 6.5 years after planting were not significantly affected by stand density for either *L. diversifolia* or *L. leucocephala*. Mean yields obtained from *L. leucocephala* were significantly more than those of *L. diversifolia* at the ages of 2.5 and 6.5 years (Appendix 5, Table 13), i.e. 3.2 vs. 2.5 tonnes ha^{-1} at 2.5 years and 3.13 vs. 2.21 tonnes ha^{-1} at 6.5 years. Species x spacing interaction was not significant at any of the harvests.

4.2.8.5 Total Biomass per Hectare

As with all products, total biomass of *L. leucocephala* was superior to that of *L. diversifolia* at all ages of harvest (Table 4.3, Column 7), but not statistically so at 4.5 years (Appendix 5, Table 14). At ages 2.5 and 6.5 years the p-values were 0.0028 and 0.0004 respectively. Within both species, mass in the high and medium density plots was significantly more than the mass in the low density plots at the harvest of trees aged 2.5 years. The mass harvested 4.5 and 6.5 years after planting was not significantly affected by spacing of trees (Table 4.3 Column 7).

Species x spacing interaction was not significant at any of the harvests (Appendix 5, Table 14).

4.2.9 Simple Statistical Correlations for Exotic Species

The correlation coefficients of exotic tree species for all parameters are presented in Appendix 5, Table 15. Table 4.4 shows correlations of harvested biomass of agroforestry products.

Table 4.4 Correlation coefficients of L. diversifolia *and* L. leucocephala *agroforestry products*

Parameter	*L. diversifolia*			*L. Leucocephala*		
Lfw &	1996 (2.5)	1998 (4.5)	2000 (6.5)	1996 (2.5)	1998 (4.5)	2000 (6.5)
Pods	0.9276***	0.2964*	0.5774***	0.8661***	0.1915*	0.6506***
Wd	0.9738***	0.8204***	0.9481***	0.8946***	0.8222***	0.9591***
Pods &						
Wd	0.9234***	0.3595**	0.7191***	0.8916***	0.3770**	0.7018***

ns=not significant $p>0.05$; * significant $p\leq0.05$; **significant $p\leq0.01$; ***statistically significant at $p\leq0.001$.
Lfw = leaf mass; Pods = pod mass; Wd = wood mass

As shown in Table 4.4, the association between leaf and pod mass was highly significant, especially at the harvest of 1996 and 2000 which followed seasons of high rainfall (Appendix 2, Table 1). This was true for both *L. diversifolia* and for *L. leucocephala* with significant correlation in 1998 and highly significant correlation in the two years of good rainfall. Leaf and wood mass were positively and significantly correlated in both species. Similarly there was a high correlation between pods mass and wood mass which was especially strong in the two years of good rainfall.

4.3 RESULTS OF CHEMICAL ANALYSIS OF PLANT MATERIAL

4.3.1 Nutritional Composition of the Leaves of the Four Species

4.3.1.1 General

Nutritional composition of oven-dried leaves of the four species in g/100 g of dry matter is presented in Table 4.5. The results show great variation in digestibility and mineral content among leaves of the four species. Analysis of variance is presented in Appendix 6, Table 1.

Table 4.5 Nutritional composition of leaves of the four species (g/100 g of DM)

Parameter	Spacing	*A. galpinii*	*F. albida*	*L. diversifolia*	*L.leucocephala*
ADF	5.0	38.93 ± 5.37	28.35 ± 4.10	36.44 ± 6.28	28.44 ± 7.41
	6.3	37.93 ± 8.48	29.71 ± 4.58	31.79 ± 6.76	26.98 ± 6.74
	8.3	36.51 ± 10.12	31.57 ± 6.59	27.40 ± 9.48	34.11 ± 5.01
Mean		**37.79a**	**29.88c**	**31.88b**	**29.85c**
ADL	5.0	17.53 ± 6.37	11.24 ± 2.75	15.92 ± 7.37	9.73 ± 5.94
	6.3	17.66 ± 4.92	12.77 ± 3.67	12.12 ± 2.01	10.68 ± 4.40
	8.3	17.43 ± 7.80	11.65 ± 2.79	10.13 ± 3.04	12.68 ± 5.31
Mean		**17.54a**	**11.89bc**	**12.72b**	**11.03c**
Ash	5.0	6.33 ± 1.06	4.75 ± 0.25	5.72 ± 1.10	7.37 ± 1.02
	6.3	7.02 ± 1.01	4.45 ± 0.87	5.23 ± 1.48	7.22 ± 1.14
	8.3	6.05 ± 0.74	4.52 ± 0.19	6.49 ± 1.08	7.50 ± 0.89
Mean		**6.47b**	**4.58d**	**5.81c**	**7.36a**
CP	5.0	18.97 ± 4.02	26.1 0± 3.34	16.17 ± 2.27	17.18 ± 4.15
	6.3	18.31 ± 2.64	25.22 ± 3.71	15.48 ± 3.63	17.83 ± 4.49
	8.3	18.89 ± 5.00	24.41 ± 6.11	17.12 ± 4.02	16.30 ± 2.86
Mean		**18.72b**	**25.25a**	**16.26d**	**17.11c**
IVDMD	5.0	74.76 ± 4.24	80.48 ± 2.75	76.62 ± 2.55	81.36 ± 3.06
	6.3	76.02 ± 2.55	78.11 ± 2.74	75.13 ± 5.37	82.45 ± 2.69
	8.3	73.96 ± 4.80	80.41 ± 2.28	77.08 ± 1.59	83.45 ± 3.33
Mean		**74.91d**	**79.67b**	**76.28c**	**82.28a**
NDF	5.0	33.47 ± 5.62	33.52 ± 5.24	34.62 ± 8.04	34.35 ± 6.85
	6.3	33.64 ± 6.09	30.43 ± 4.97	33.13 ± 4.87	34.67 ± 6.63
	8.3	33.85 ± 6.52	30.05 ± 7.21	36.09 ± 6.19	34.04 ± 6.90
Mean		**33.65a**	**31.19b**	**34.36a**	**34.61a**
OM	5.0	93.67 ± 1.06	95.28 ± 0.14	94.24 ± 1.16	92.63 ± 1.02
	6.3	92.98 ± 1.01	95.52 ± 0.87	94.77 ± 1.48	92.92 ± 1.05
	8.3	93.95 ± 0.74	95.48 ± 0.19	93.51 ± 1.08	92.50 ± 0.89
Mean		**93.53c**	**95.43a**	**94.17b**	**92.68d**
Tannin	5.0	2.30 ± 0.77	1.58 ± 1.02	2.43 ± 0.57	1.84 ± 0.66a
	6.3	1.95 ± 1.064	2.32 ± 0.83	2.07 ± 0.67	1.81 ± 0.33
	8.3	2.16 ± 1.09	1.75 ± 0.38	1.63 ± 0.57	2.69 ± 2.04
Mean		**2.14a**	**1.89b**	**2.04a**	**2.12a**

Means followed by a different letter **abcd** along the row show significant differences among species for relevant parameter

4.3.1.2 Acid Detergent Fibre (ADF)

The difference among species was highly significant ($p<0.0001$) as shown in Appendix 6, Table 1. The contrast been the mean values of trees at different plot densities was statistically significant ($p = 0.0231$). Species x spacing interaction was significantly different ($p<0.0001$).

Acid detergent fibre was highest for *A. galpinii* followed by *L. diversifolia*, while *F. albida* had a very similar value to that of *L. leucocephala* (Table 4.5). The mean values for the four species were 37.79, 31.88, 29.88 and 29.845 g/100 g of dry matter respectively (Table 4.5).

4.3.1.3 Acid Detergent Lignin (ADL)

As shown in Appendix 6, Table 1, the difference in ADL among the leaves of the four species was statistically significant ($p<0.0001$). ADL was highest in *A. galpinii*, while *L. leucocephala* had the lowest ADL. The mean values for the four species were 17.54, 12.72, 11.89 and 11.03 g/100 g of dry matter in the case of *A. galpinii*, *L. diversifolia*, *F. albida* and *L. leucocephala* respectively (Table 4.5).

Spacing did not influence ADL values ($p = 0.2659$). Species x spacing interaction was highly significant ($p<0.0001$). For *L. leucocephala* the mean of the low density stands was greater than those of medium and high density plots, while with *A. galpinii* means of different spacings did not vary greatly. The mean of the medium density *F. albida* plots was greatest and that of high density plantings was lowest. With *L. diversifolia* ADL values were highest in high density plots and lowest in low density stands (Table 4.5).

4.3.1.4 Ash Content

The differences among the four species were statistically significant ($p<0.0001$) (Appendix 6, Table 1). Ash content was greatest in *L. leucocephala,* followed by *A. galpinii,* and *F. albida* had the lowest value (Table 4.5). The ash content of *L. leucocephala* was 7.36 g/100 g of dry

matter, while *A. galpinii, L. diversifolia* and *F. albida* had values of 6.47, 5.81 and 4.58 g/100 g of dry matter respectively.

Analysis of variance (Appendix 6, Table 1) shows that spacing did not influence ash content significantly. Species x spacing interaction was statistically significant ($p<0.0001$). For *A. galpinii* the ash content was highest in the medium density plots, while low density plots had the lowest value. With both *L. diversifolia* and *L. leucocephala* the mean ash values were highest in low density plots and lowest in medium density stands. The values for *F. albida* ranged from 4.45 ± 0.87 to 4.75 ± 0.25 g/100 g of dry matter, with the lowest value in medium density stands and the highest value in the high density plots.

4.3.1.5 Crude Protein (CP)

The difference in crude protein content of the leaves of the four species was highly significant ($p<0.0001$), as shown in the analysis of variance (Appendix 6, Table 1). The highest crude protein of leaves was that of *F. albida* at 25.25 g/100 g of dry matter. The values for *A. galpinii, L. leucocephala* and *L. diversifolia* were 18.72, 17.11 and 16.26 g/100 g of dry matter respectively (Table 4.5).

Spacing did not have an effect on the crude protein content of leaves. However, species x spacing interaction was statistically significant ($p = 0.0097$). With *L. diversifolia* the mean crude protein content was highest in the low density plots, while for *L. leucocephala* it was highest in medium density stands. The crude protein in the leaves of *A. galpinii* was more or less uniform among stands, ranging between 18.31 ± 2.64 and 18.97 ± 4.02 g/100 g of dry matter, whereas for *F. albida* the values were greatest in the high density plots and lowest in low density spacings.

4.3.1.6 In Vitro Dry Matter Digestibility (IVDMD)

The contrast among the means of the four species was highly significant ($p<0.0001$) (Appendix 6, Table 1). Of the four species, *L. lecucocephala* had the highest IVDMD with a value of 82.28

g/100 g of dry matter. *F. albida, L. diversifolia* and *A. galpinii* had values of 79.67, 76.28 and 74.91 g/100 g of dry matter respectively (Table 4.5).

The P-value of IVDMD at different plot densities was 0.0549. Species x spacing interaction was statistically significant ($p<0.0001$), as shown in Appendix 6, Table 1. For both *L. diversifolia* and *L. leucocephala* the mean IVDMD was greatest in low density plots. The lowest value for *L. leucocephala* was in high density plots, whereas with *L. diversifolia* it was from trees in the medium density stands. For *A. galpinii* the highest mean was in the medium density plots and the lowest in low density plantings. With *F. albida* leaves, the mean IVDMD was greatest in high density and lowest in medium density stands.

4.3.1.7 Neutral Detergent Fibre (NDF)

Appendix 6, Table 1 shows analysis of variance results. The difference between species was statistically significant ($p<0.0001$). Overall NDF means and means at different spacings of the four species are presented in Table 4.5. The values were 34.61, 34.36, 33.65 and 31.19 g/100 g of dry matter, for *L. diversifolia, L. leucocephala, A. galpinii* and *F. albida* respectively. Means at contrasting plot densities were not significantly different ($p = 0.3469$). Species x spacing interaction was not significantly different ($p = 0.1058$).

4.3.1.8 Organic Matter (OM)

The differences in the OM content of leaves of the four species were statistically significant ($p<0.0001$), as shown in Appendix 6, Table 1. Organic matter was highest in *F. albida* at 95.43 g/100 g of dry matter. *L. diversifolia, A. galpinii and L. leucocephala* had values of 94.17, 93.53 and 92.68 g/100 g of dry matter respectively.

The P-value for comparison of OM content at different spacings was 0.0593. Species x spacing interaction was statistically significant ($p<0.0001$). With the exception of *A. galpinii,* the value for organic matter was greatest in the leaves of trees in the medium density plots. The lowest values for both *L. diversifolia* and *L. leucocephala* were in the low density stands. For *A.*

galpinii the greatest mean was in the low density plots and the lowest in the medium density plantings (Table 4.5).

4.3.1.9 Condensed Tannin (CT)

Condensed tannin content varied significantly among the four species with a P-value of 0.0033 (Appendix 6, Table 1). The tannin contents of the leaves of the four species were 2.14, 2.12, 2.04 and 1.89 g/100 g of dry matter for *A. galpinii, L. leucocephala, L. diversifolia* and *F. albida* respectively. Spacing did not influence the tannin content of leaves (p = 0.9328). However, species x spacing interaction was statistically significant (p<0.0001). The mean values of *L. diversifolia* and *A. galpinii* were greatest in high density plots, while with *L. leucocephala* the mean was greatest at low density plantings. *F. albida* had the highest mean in medium density plots.

4.3.2 Mineral Composition of the Leaves of the Four Species

Mineral composition of leaves of the four species are presented in Table 4.6

Table 4.6 Mineral content of leaves of the four species (g/100 g of DM)

Parameter	Spacing	*A. galpinii*	*F. albida*	*L.. diversifolia*	*L. .leucocephala*
Ca	5.0	0.84 ± 0.32	0.46 ± 0.13	0.97 ± 0.36	0.80 ± 0.42
	6.3	1.31 ± 0.48	0.59 ± 0.23	0.87 ± 0.36	1.08 ± 0.37
	8.3	1.43 ± 0.50	0.56 ± 0.27	0.95 ± 0.56	1.23 ± 0.43
Mean		**1.20a**	**0.54d**	**0.93c**	**1.04b**
K	5.0	0.54 ± 0.39	0.45 ± 0.20	0.55 ± 0.36	0.75 ± 0.67
	6.3	0.57 ± 0.27	0.51 ± 0.29	0.50 ± 0.41	0.48 ± 0.27
	8.3	0.83 ± 0.49	0.77 ± 0.43	0.45 ± 0.19	0.58 ± 0.40
Mean		**0.65a**	**0.58b**	**0.50c**	**0.61ba**
Mg	5.0	0.53 ± 0.17	0.26 ± 0.02	0.38 ± 0.07	0.68 ± 0.10
	6.3	0.61 ± 0.19	0.30 ± 0.13	0.34 ± 0.11	0.56 ± 0.17
	8.3	0.46 ± 0.13	0.27 ± 0.06	0.38 ± 0.19	0.69 ± 0.08
Mean		**0.53b**	**0.27d**	**0.37c**	**0.64a**
Na	5.0	0.0026 ± 0.0012	0.0032 ± 0.0026	0.0027 ± 0.0014	0.0029 ± 0.0016
	6.3	0.0025 ± 0.0012	0.0025 ± 0.0023	0.0022 ± 0.001	0.0027 ± 0.0010
	8.3	0.0030 ± 0.0011	0.0025 ± 0.001	0.0026 ± 0.0013	0.0025 ± 0.0012
Mean		**0.00272b**	**0.0030a**	**0.00252c**	**0.00271b**
P	5.0	0.20 ± 0.07	0.25 ± 0.10	0.15 ± 0.05	0.20 ± 0.07
	6.3	0.19 ± 0.05	0.25 ± 0.06	0.17 ± 0.06	0.20 ± 0.06
	8.3	0.18 ± 0.07	0.24 ± 0.10	0.20 ± 0.08	0.16 ± 0.05
Mean		**0.19b**	**0.24a**	**0.17c**	**0.19b**

Means followed by a different letter along the row show significant differences between species

4.3.2.1 Calcium Content (Ca)

The difference in calcium content among leaves of the four species was statistically significant ($p<0.0001$), as shown in Appendix 6, Table 2. Spacing influenced calcium concentration significantly ($p<.0001$). Species x spacing interaction was also statistically significant ($p<0.0001$).

A. galpinii had the highest mean calcium concentration at 1.20 g/100 g of dry matter, while *F. albida* had the lowest value at 0.54 g/100 g of dry matter (Table 4.6). The values for *L. leucocephala,* and *L. diversifolia* differed less than for the two indigenous trees, being 1.04 and 0.93 g/100 g of dry matter respectively.

Both *A. galpinii* and *L. leucocephala* had the highest mean value in the low density spacings and the lowest in the high density stands. With *F. albida* the highest mean of calcium content was in the medium density plots and the lowest in high density stands. The highest concentration of calcium in *L. diversifolia* leaves was in high density plantings and the lowest in medium density stands (Table 4.6).

4.3.2.2 Potassium Content (K)

The contrast in potassium content among the leaves of the four species was statistically significant ($p<0.0001$) (Appendix 6, Table 2). Of the four species, leaves of *A. galpinii* had the highest potassium concentration at 0.65 g/100 g of dry matter, while *L. leucocephala* had a higher value than *F. albida* and *L. diversifolia*. These three species had potassium contents of 0.61, 0.58 and 0.50 g/100 g of dry matter respectively *(*Table 4.6). The difference in concentration among planting densities was also highly significant ($p<0.0001$), as was species x spacing interaction ($p<0.0001$), as shown in Appendix 6, Table 2. Concentration of the mineral varied among planting densities. *A. galpinii* and *F. albida* displayed the highest concentrations in low density plots and the lowest in high density plantings. *L. diversifolia* and *L. leucocephala* trees at high density plantings had the highest potassium concentration. The lowest value for *L.*

diversifolia was in the low density plots, while the medium density stands had the lowest mean for *L. leucocephala.*

4.3.2.3 Magnesium Content (Mg)

The difference in magnesium concentration among the leaves of the four species was highly significant ($p<0.0001$) (Appendix 6, Table 2). The highest concentration of magnesium in leaves, at 0.64 g/100 g of dry matter, was in *L. leucocephala* and the lowest value was exhibited by *F. albida* at 0.27 g/100 g of dry matter. *A. galpinii* and *L. diversifolia* had values of 0.53 and 0.37 g/100 g of dry matter respectively (Table 4.6). Spacing influenced magnesium concentration marginally ($p = 0.0694$). Species x spacing interaction was statistically significant ($p<0.0001$), as shown in Appendix 6, Table 2. *A. galpinii* and *F. albida* had mean values of magnesium concentration highest in the medium density plots, while low density plots had the lowest means. In contrast, with *L. diversifolia* and *L. leucocephala* the lowest concentration was in the leaves of trees grown in the medium density stands, while leaves from high and low density plots had similar means (Table 4.6).

4.3.2.4 Sodium Content (Na)

Analysis of variance (Appendix 6, Table 2) shows that the contrast in sodium content among the leaves of the four species was highly significant ($p<0.0001$). The sodium concentration in leaves of the four species was 0.0030, 0.0027, 0.0025, and 0.0027 g/100 g of dry matter for *F. albida, L. leucocephala*, *L. diversifolia* and *A. galpinii* respectively. The differences in concentration were highly significant among plot densities ($p<0.0001$). Species x spacing interaction was also highly significant ($p<0.0001$). For *A. galpinii* the sodium content was highest in low density spacings and lowest in the medium density stands, while for *F. albida* the highest value was from trees at high density and the medium and low density plots had similar values. With both *L. diversifolia* and *L. leucocephala* the highest concentration was in high density stands. The lowest value for *L. diversifolia* was in the medium density plantings, in contrast to *L. leucocephala* whose lowest mean was in low density plots (Table 4. 6).

4.3.2.5 Phosphorus Content (P)

The difference in phosphorus content among leaves of the four species was highly significant ($p<0.0001$) (Appendix 6, Table 2). The leaves of *F. albida* had the highest phosphorus concentration with a value of 0.24 g/100 g of dry matter, while A. *galpinii* and *L. leucocephala* had identical amounts, with values of 0.19 g/100 g of dry matter. *L. diversifolia* had the lowest phosphorus concentration at 0.17 g/100 g of dry matter (Table 4.6). The concentration at different spacings was not significantly different ($p = 0.4994$) (Appendix 6, Table 2). Species x spacing interaction was highly significant ($p<0.0001$) as shown in Appendix 6, Table 2. *A. galpinii*, *F. albida* and *L. leucocephala* exhibited the highest phosphorus concentration in high density plots and the lowest in low density plantings, while for *L. diversifolia* the highest concentration was in low density plots and the lowest in high density stands (Table 4.6).

4.3.3 Comparison of Chemical Composition of Leaves and Pods of Exotic Trees

4.3.3.1 General

The results of the analysis of nutritional composition, on a dry matter basis, of leaves and pods of *L. diversifolia* are presented in Table 4.7. Analysis of variance results are displayed in Appendix 6, Table 3. *L. leucocephala* means are shown in Table 4.8 and analysis of variance in Appendix 6, Table 4. For both species the results show that there were significant differences in chemical composition between the leaves and pods of the same species.

Variations in the mineral composition of leaves and pods are contrasted in Table 4.9 for *L. diversifolia* and in Table 4.10 in the case of *L. leucocephala.* Analysis of variance results are presented in Appendix 6, Table 5 and Table 6 for the two species respectively.

Table 4.7 Nutritional composition of leaves and pods of L. diversifolia (g/100 g of DM)

Parameter	Spacing	Leaves	Pods
ADF	5.0	36.44 ± 6.28	36.11 ± 6.31
	6.3	31.79 ± 6.76	33.42 ± 5.40
	8.3	27.40 ± 9.48	40.28 ± 6.46
Mean		**31.88b**	**36.60a**
ADL	5.0	15.92 ± 7.37	13.66 ± 2.83
	6.3	12.12 ± 2.01	11.27 ± 2.48
	8.3	10.13 ± 3.04	13.83 ± 3.34
Mean		**12.72a**	**12.92a**
Ash	5.0	5.72 ± 1.10	4.90 ± 0.44
	6.3	5.23 ± 1.48	5.05 ± 0.37
	8.3	6.49 ± 1.08	5.36 ± 1.47
Mean		**5.81a**	**5.10b**
CP	5.0	16.17 ± 2.27	18.00 ± 2.49
	6.3	15.48 ± 3.63	17.53 ± 2.86
	8.3	17.12 ± 4.02	17.01 ± 2.53
Mean		**16.26b**	**17.51a**
IVDMD	5.0	76.62 ± 2.55	68.36 ± 3.83
	6.3	75.13 ± 5.37	72.01 ± 4.31
	8.3	77.08 ± 1.59	67.67 ± 3.34
Mean		**76.28a**	**69.34b**
	5.0	34.62 ± 8.04	39.14 ± 4.25
NDF	6.3	33.13 ± 4.87	36.39 ± 6.49
	8.3	36.09 ± 6.19	38.39 ± 5.72
		34.61b	**37.97a**
OM	5.0	94.24 ± 1.16	95.10 ± 0.45
	6.3	94.77 ± 1.48	94.92 ± 0.36
	8.3	93.51 ± 1.08	94.48 ± 1.45
Mean		**94.17b**	**94.83a**
Tannin	5.0	2.43 ± 0.57	2.82 ± 1.78
	6.3	2.07 ± 0.67	2.42 ± 0.91
	8.3	1.63 ± 0.57	1.89 ± 0.69
Mean		**2.04b**	**2.38a**

Means followed by a different letter **ab** along the row show significant difference between parts

Table 4.8 Nutritional composition of leaves and pods of L. leucocephala (g/100 g of DM)

Parameter	Spacing	Leaves	Pods
ADF	5.0	34.11 ± 5.01	32.80 ± 5.55
	6.3	26.98 ± 6.74	35.48 ± 6.44
	8.3	28.44 ± 7.41	34.94 ± 6.61
Mean		**29.84b**	**34.40a**
ADL	5.0	9.73 ± 5.94	11.04 ± 2.83
	6.3	10.68 ± 4.41	12.28 ± 2.95
	8.3	12.68 ± 5.31	11.90 ± 3.44
Mean		**11.03a**	**11.74a**
Ash	5.0	7.37 ± 1.02	5.62 ± 0.31
	6.3	7.22 ± 1.14	5.72 ± 0.50
	8.3	7.50 ± 0.89	6.40 ± 1.53
Mean		**7.36a**	**5.92b**
CP	5.0	17.18 ± 4.15	19.24 ± 3.32
	6.3	17.83 ± 4.49	20.01 ± 3.00
	8.3	16.30 ± 2.86	19.91 ± 3.42
Mean		**17.11b**	**19.72a**
IVDMD	5.0	81.36 ± 3.06	72.92 ± 3.77
	6.3	82.45 ± 2.69	72.81 ± 3.19
	8.3	83.45 ± 3.33	74.42 ± 4.30
Mean		**82.28a**	**73.39b**
NDF	5.0	34.35 ± 6.85	39.50 ± 3.93
	6.3	34.67 ± 6.62	37.42 ± 5.81
	8.3	34.04 ± 6.90	38.99 ± 3.49
		34.36b	**38.64a**
OM	5.0	92.63 ± 1.02	94.38 ± 0.31
	6.3	92.92 ± 1.05	94.28 ± 0.50
	8.3	92.50 ± 0.89	93.66 ± 1.52
Mean		**92.68b**	**94.11a**
Tannin	5.0	1.84 ± 0.66	2.49 ± 1.46
	6.3	1.81 ± 0.33	2.12 ± 0.62
	8.3	2.69 ± 2.04	2.16 ± 0.73
Mean		**2.12b**	**2.25a**

Means followed by a different letter **ab** along the row show significant differences between parts

4.3.3.2 Acid Detergent Fibre (ADF)

Analysis of variance (Appendix 6, Table 4) shows that the difference in ADF between pods and leaves of *L. diversifolia* was statistically significant ($p<0.0001$). The mean values were 36.60 and 31.88 g/100 g of dry matter respectively (Table 4.7). ADF at contrasted spacings was highly significant ($p<0.0001$). Part x spacing interaction was also statistically significant ($p<0.0001$). ADF was highest in the high density plots and lowest in low density plantings for leaves, while the greatest mean for pods was in low density spacings and the lowest in trees at medium density.

With *L. leucocephala* ADF was also significantly different and greatest in pods, with a value of 34.40 g/100 g of dry matter in contrast to 29.84 g/100 g of dry matter for the leaves ($p<0.0001$). Contrasts in the mean values of ADF at different spacings were highly significant ($p <0.0001$).

Part x spacing interaction was also statistically significant ($p < 0.0001$), as presented in Appendix 6, Table 3. The highest mean value for pods was from trees in medium density plots and the lowest at high density plantings, while for leaves the mean value was greatest at high density and lowest in the medium density plots (Table 4.8).

4.3.3.3 Acid Detergent Lignin (ADL)

The ADL concentration of *L. diversifolia* pods and leaves did not differ significantly ($p = 0.5782$). The difference in mean values at contrasting spacings was highly significant ($p<0.0001$), as was part x spacing interaction (Appendix 6, Table 3). For pods the mean ADL value was greatest in low density plots and lowest in the medium density stands, while with leaves the mean value was greatest at high density and lowest in the low density plantings (Table 4.7).

For *L. leucocephala* ADL concentration was also not significantly different between pods and leaves as shown in Appendix 6 Table 4 ($p = 0.1110$). However, mean values among contrasting plot densities were statistically significant ($p = 0.0027$). Part x spacing interaction was also statistically significant ($p<0.0001$), as shown in Appendix 6, Table 4. The mean value of ADL in pods was greatest in the medium density plots and lowest at low density, while for leaves the highest value was in low density plots and the lowest at high density plots (Table 4.8).

4.3.3.4 Ash Content

Analysis of variance (Appendix 6, Table 3) shows that for *L. diversifolia* the difference between the ash content of the two parts was statistically significant ($p < 0.0001$), as was the concentration at contrasting spacings ($p < .0001$). Spacing x part interaction was also statistically significant ($p = 0.0213$). The ash content of *L. diversifolia* was 5.81 g/100 g of dry matter in leaves, in contrast with that of pods with a mean value of 5.10 g/100 g of dry matter. The mean value for leaves was greatest in low density spacings and lowest in the medium density plots, at 7.50 ± 0.89 and 7.22 ± 1.14 g/100 g of dry matter respectively (Table 4.7). For pods the highest mean was in low

density plantings and the lowest in high density plots, with values of 6.40 ± 1.53 and 5.62 ± 0.31 g/100 g of dry matter respectively.

Analysis of variance (Appendix 6, Table 4) shows that the difference between parts was also statistically significant ($p<0.0001$) for *L. leucocephala*. As with *L. diversifolia,* the ash content of *L. leucocephala* was greater in leaves compared to that of the pods, the mean values being 7.36 and 5.92 g/100 g of dry matter respectively. Differences in values among contrasting spacings were also significant ($p<0.0001$), as was part spacing ($p<0.0001$) (Appendix 6, Table 4). At contrasting spacings the value was greatest for leaves in the low density plantings and lowest in medium density plots, while for pods the mean value was greatest in the low density plots but lowest in high density stands (Table 4.8).

4.3.3.5 Crude Protein (CP)

The difference between the crude protein content of the parts was highly significant ($p <0.0001$), but spacing did not influence the crude protein content of the two parts. With a mean of 17.51 g/100 g of dry matter, pods of *L. diversifolia* had a greater crude protein content than the leaves which had a mean value of 16.25 g/100 g of dry matter. Part x spacing interaction was significant ($p = 0.0007$), as shown in Appendix 6, Table 3. The highest mean value for the crude protein content of the leaves was in low density plots and the lowest in the medium density stands, while for pods the greatest mean was in trees planted at high density and lowest in the low density plots (Table 4.7).

Appendix 6, Table 4 shows that the difference in the crude protein content of the leaves and pods of *L. leucocephala* was statistically significant ($p<0.0001$). The crude protein of *L. leucocephala* was higher in pods, at 19.72 g/100 g of dry matter, compared to a value of 17.11 g/100 g of dry matter for leaves. The crude protein varied significantly at contrasted spacings ($p = 0.0258$). Part x spacing interaction was significant ($p = 0.0322$). Mean values were greatest in the medium density plots for both parts, but the lowest mean for pods was in the high density plantings while for leaves the mean was lowest in low density plots (Table 4.8).

4.3.3.6 In Vitro Dry Matter Digestibility (IVDMD)

The difference in IVDMD between pods and leaves of *L. diversifolia* was statistically significant ($p < 0.0001$). In vitro dry matter digestibility of *L. diversifolia* was greater in the leaves, with a value of 76.28 g/100 g of dry matter compared to 69.34 g/100 g of dry matter in pods. The digestibility values were significantly different among spacings ($p = 0.0203$). For leaves the mean value for IVDMD was greatest in trees at low density and lowest in the medium density stands. Spacing x part interaction was statistically significant ($p<0.0001$), as demonstrated in Appendix 6, Table 3. With pods the mean was highest in the medium density plots and lowest in low density stands (Table 4.7).

The difference between leaves and pods of *L. leucocephala* was highly significant ($p<0.0001$), and there were also significant differences in IVDMD at contrasted spacings ($p = 0.0049$). Part x spacing interaction was not statistically significant (Appendix 6, Table 4). As with *L. diversifolia*, the value for IVDMD of *L. leucocephala* was greater in the leaves than in pods, being 82.28 and 73.37 g/100 g of dry matter respectively. Means for both parts were greatest in the low density plots, but for leaves the mean value was lowest in the high density plantings, while for pods the lowest value was in the medium density stands (Table 4.8).

4.3.3.7 Neutral Detergent Fibre (NDF)

The difference in NDF for the parts of *L. diversifolia* was statistically significant ($p<0.0001$) (Appendix 6, Table 3). NDF values for leaves and pods of *L. diversifolia* were 34.61 and 37.97 g/100 g of dry matter respectively. The influence of spacing was also significant ($p = 0.0016$). At different spacings the mean value for pods was greatest in high density plots and lowest in the medium density stands. In contrast, for leaves the mean was greatest in medium density plantings and lowest in the low density plots (Table 4.7). Part x spacing interaction was not significant ($p = 0.8881$).

With *L. leucocephala* the difference between leaves and pods was statistically significant ($p<0.0001$) (Appendix 6, Table 3) with the NDF value greater in pods than in the leaves, with values of 38.64 and 34.36 g/100 g of dry matter respectively (Table 4.8). Spacing did not influence percentage NDF significantly ($p = 0.5052$). Part x spacing interaction was not statistically significant ($p = 0.2092$).

4.3.3.8 Organic Matter (OM)

The organic matter content in leaves and pods of *L. diversifolia* was significantly different ($p<0.0001$) (Appendix 6, Table 3) with a value of 94.83 g/100 g of dry matter for pods compared to 94.17 g/100 g of dry matter for the leaves (Table 4.7). At contrasted spacings the difference in OM was also significant ($p<0.0001$), as was part x spacing interaction ($p = 0.00389$). For pods, trees at high density had the highest value while those at low density had the lowest mean. The highest mean for the leaves was in the medium density plots and the lowest in low density spacing.

Analysis of variance (Appendix 6, Table 4) shows that with *L. leucocephala* the organic matter content of pods was significantly more than that of leaves ($p<0.0001$), with values of 92.68 and 94.10 g/100 g of dry matter for leaves and pods respectively. Means at contrasted plot densities were also significantly different ($p<0.0001$). Part x spacing interaction was statistically significant ($p<0.0001$). The highest mean for leaves was from trees at medium density, while for pods the lowest was from low density stands and the highest in high density plots (Table 4.8).

4.3.3.9 Condensed Tannin (CT)

Appendix 6, Table 3 shows that the difference in tannin content of leaves and pods of *L. diversifolia*, with concentrations of 2.04 and 2.38 g/100 g of dry matter respectively was statistically significant, as were the differences among contrasting spacings ($p<0.0001$). The mean values of both leaves and pods were greatest in the high density plots and lowest in low density stands (Table 4.7). Part x spacing interaction was not significant ($p = 0.7001$)

The difference between parts was significant (p = 0.0182) for *L. leucocephala*. As with *L. diversifolia*, the tannin content in the pods of *L. leucocephala* was greater than in its leaves, with concentrations of 2.15 and 2.12 g/100 g of dry matter respectively. The tannin concentration at contrasted spacings was significant, as was part x spacing interaction (p<0.0001) (Appendix 6, Table 4). At contrasting spacings the mean for leaves was greatest from trees in low density plots and lowest in those from medium density spacings. The concentration in pods was greatest in those from high density plantings and lowest from trees grown at medium density.

4.3.4 Comparison of Mineral Composition of Leaves and Pods of Exotic Species

Mineral concentration of leaves and pods of *L. diversifolia* are contrasted in Table 4.9 while those of *L. leucocephala* are shown in Table 4.10

Table 4.9 Mineral content of leaves and pods of L. diversifolia *(g/100 g of DM)*

Parameter	Spacing	Leaves	Pods
Ca	5.0	0.97 ± 0.36	0.27 ± 0.09
	6.3	0.87 ± 0.36	0.36 ± 0.15
	8.3	0.95 ± 0.55	0.43 ± 0.17
Mean		**0.93a**	**0.36b**
K	5.0	0.55 ± 0.36	0.49 ± 022
	6.3	0.50 ± 0.40	0.68 ± 0.37
	8.3	0.46 ± 0.19	0.89 ± 0.58
Mean		**0.50b**	**0.69a**
Mg	5.0	0.38 ± 0.07	0.24 ± 0.05
	6.3	0.34 ± 0.11	0.26 ± 0.07
	8.3	0.38 ± 0.19	0.31 ± 0.07
Mean		**0.37a**	**0.27b**
Na	5.0	0.0027 ± 0.0014	0.0037 ± 0.0023
	6.3	0.0022 ± 0.0008	0.0038 ± 0.0017
	8.3	0.0026 ± 0.0013	0.0034 ± 0.0020
Mean		**0.0025b**	**0.0036a**
P	5.0	0.15 ± 0.05	0.23 ± 0.05
	6.3	0.17 ± 0.06	0.22 ± 0.04
	8.3	0.20 ± 0.08	0.23 ± 0.07
Mean		**0.17b**	**0.23a**

Means followed by a different letter **ab** along the row show significant difference between parts

Table 4. 10 Mineral content of leaves and pods of L. leucocephala (g/100 g of DM)

Parameter	Spacing	Leaves	Pods
Ca	5.0	0.80 ± 0.42	0.53 ± 0.19
	6.3	1.08 ± 0.37	0.54 ± 0.17
	8.3	1.23 ± 0.43	0.50 ± 0.16
Mean		**1.04a**	**0.52b**
K	5.0	0.75 ± 0.22	0.60 ± 0.19
	6.3	0.48 ± 0.26	0.51 ± 0.22
	8.3	0.58 ± 0.40	0.63 ± 0.21
Mean		**0.61a**	**0.58a**
Mg	5.0	0.68 ± 0.10	0.35 ± 0.06
	6.3	0.56 ± 0.17	0.42 ± 0.13
	8.3	0.69 ± 0.08	0.32 ± 0.06
Mean		**0.64a**	**0.36b**
Na	5.0	0.0029 ± 0.0016	0.0031 ± 0.0021
	6.3	0.0027 ± 0.0010	0.0034 ± 0.0020
	8.3	0.0025 ± 0.0012	0.0035 ± 0.0019
Mean		**0.0027b**	**0.0034a**
P	5.0	0.20 ± 0.07	0.28 ± 0.06
	6.3	0.20 ± 0.06	0.22 ± 0.06
	8.3	0.16 ± 0.05	0.26 ± 0.06
Mean		**0.19b**	**0.25a**

Means followed by a different letter **ab** along the row show significant difference between parts

4.3.4.1 Calcium Content (Ca)

The contrast between leaves and pods of *L. diversifolia* (Appendix 6, Table 5) was statistically significant ($p<0.0001$). The mean calcium concentration in leaves was 0.93 g/100 g of dry matter and that of pods was 0.36 g/100 g of dry matter (Appendix 6, Table 5). There were no significant differences in calcium content at different spacings ($p = 0.1883$). Part x spacing interaction was not statistically significant but P-value was low ($p = 0.0511$) (Appendix 6, Table 5). With pods, values were highest for trees at low density and lowest in the high density stands (Table 4.9). While for leaves highest value was in high density and lowest in medium density plots.

As with the calcium concentration of *L. diversifolia,* leaves of *L. leucocephala* had a significantly higher content of the mineral, with a value of 1.04 g/100 g of dry matter, than the pods, whose mean was 0.52 g/100 g of dry matter ($p<0.0001$) (Appendix 6, Table 6). Part x spacing interaction was also highly significant ($p<0.0001$). At contrasted spacings leaves had the highest calcium content in the low density plots, while the lowest value was from leaves of trees at high density. The mean value for pods was highest in the medium density spacings and lowest in the low density stands.

4.3.4.2 Potassium Content (K)

Analysis of variance (Appendix 6, Table 5) shows that the difference in potassium concentration between leaves and pod of *L. diversifolia* was statistically significant ($p<0.0001$). The potassium content was higher in the pods of *L. diversifolia,* with a value of 0.69 g/100 g of dry matter, compared to 0.50 g/100 g of dry matter in the leaves (Table 4.9). The concentration was significantly influenced by spacing ($p<0.0001$), as was part x spacing interaction which was also statistically significant ($p<00001$). The concentration was greatest in the leaves of trees at high density and lowest in the low density plots; conversely, for pods the potassium content was greatest in low density plots and lowest in high density stands.

With *L. leucocephala* the potassium concentration in leaves was 0.61 and 0.58 g/100 g of dry matter in pods and was not significantly different ($p = 0.1697$) (Appendix 6, Table 6). However, the concentration among trees at different planting densities was highly significant ($p<0.0001$). Part x spacing was also highly significant ($p<0.0001$), as presented in Appendix 6, Table 6. At different spacings the highest concentration in the pods was in the low density plots, but for leaves the highest mean value was from high density spacings (Table 4.10). Both parts had the lowest means in the medium density stands.

4.3 4.3 Magnesium Content (Mg)

The difference between the concentrations of magnesium in leaves and pods of *L. diversifolia* was statistically significant ($p<0.0001$). Magnesium was more abundant in the leaves of *L. diversifolia,* with a value of 0.37 g/100 g of dry matter in contrast to a mean of 0.27 g/100 g of dry matter in the pods (Table 4.9). The mineral content at contrasted densities was also highly significant ($p<0.0001$), as was part x spacing interaction (Appendix 6, Table 5). The mean value of leaves from high density spacings was similar to that of the low density plots, while those from medium density plantings contained the lowest magnesium content. With pods, the highest concentration was in low density plots and the lowest from trees at high density.

As with *L. diversifolia*, the difference in the magnesium content of *L. leucocephala* leaves and pods was highly significant ($p<0.0001$), as shown in Appendix 6, Table 6. Magnesium was greater in the leaves than in the pods, with values of 0.64 and 0.36 g/100 g of dry matter respectively. There were significant differences in the mean values at different spacings ($p = 0.0005$) (Appendix 6, Table 6). Part x spacing interaction was statistically significant ($p<0.0001$). The highest concentration was in leaves from low density plots and the lowest from trees at medium density (Table 4.10). In contrast, pods had the highest mean value from trees at medium density and the lowest from low density spacings.

4.3.4.4 Sodium Content (Na)

The difference in sodium concentration between leaves and pods of *L diversifolia* was statistically significant ($p<0.0001$). The mean sodium concentration of *L. diversifolia* was greater in the pods, with a value of 0.0036 g/100 g of dry matter, in contrast to 0.0025 g/100 g of dry matter in the leaves (Table 4.9). Spacing did not influence sodium concentration significantly ($p = 0.4203$). Part x spacing interaction was significant ($p = 0.0211$), as shown in Appendix 6, Table 5. The sodium content was highest from the pods of trees at medium density and lowest in the low density stands.

As with *L. diversifolia*, the concentration of sodium in *L. leucocephala* was significantly greater in the pods, than in leaves ($p<0.0001$) (Appendix 6, Table 6). The values were of 0.0033 g/100 g of dry matter in pods, compared to 0.0027 g/100 g of dry matter in the leaves (Table 4.10). Differences among contrasted planting densities were not significant ($p = 0.3976$). Part x spacing interaction was statistically significant ($p<0.0001$). At different spacings the sodium content was highest in pods from low density plots and lowest from those of trees grown at high density. Conversely, for leaves, the mean value was greatest from trees at high density and lowest for those in low density plots.

4.3.4.5 Phosphorus Content (P)

With *L. diversifolia*, the difference in phosphorus concentration was significantly greater in pods than in leaves ($p<0.0001$), with values of 0.23 and 0.17 g/100 g of dry matter respectively. The contrast in concentration among plot densities was also statistically significant ($p<0.0001$), as was part x spacing interaction was ($p<.0001$), as shown in Appendix 6, Table 5. At different spacings the phosphorus value was greatest in the leaves from low density plots and lowest in those from high density stands (Table 4.9). In contrast, the lowest concentration in the pods was in those from medium density plots, while those from the high density and low density stands had similar means.

The difference between the phosphorus concentration of leaves and pods of *L. leucocephala* was statistically significant ($p<0.0001$). The mean value was greater in pods than in the leaves, with concentrations of 0.25 and 0.19 g/100 g of dry matter respectively. The concentration at contrasted spacings was highly significant, as was part x spacing interaction with a P-value of 0.0001 (Appendix 6, Table 6). The leaves from high and medium density plantings had similarly high mean values, while low density stands had the lowest concentration of phosphorus. Pods from trees in high density plots had the highest mean value, with the lowest from the medium density stands (Table 4.10).

4.4 CHEMICAL COMPOSITION OF FEED GIVEN TO LAMBS DURING TRIAL

4.4.1 General

Section 3.5.2.1 gives the proportion of browse from pods and leaves of both exotic tree species on a mass basis. Section 3.5.2.2 gives the ratio of pod to leaves of the browse in the study. The chemical composition of the feed given to the lambs from selection to the slaughter or breeding age is given in Table 4.11.

Table 4.11 Chemical composition of the experimental feeds (g/100 g of DM)

Parameter	Bran/control	Browse
ADF	32.58	30.40
ADL	4.73	5.80
Ash	8.62	6.48
CP	7.69	11.25
IVDMD	47.37	55.29
NDF	57.66	47.47
OM	91.38	93.52
Tannin	-	0.67
Ca	1.06	1.29
K	0.73	1.04
Mg	0.17	0.14
P	0.31	0.32
Na	0.004	0.033

ADF = acid detergent fibre, NDF=neutral detergent fibre, ADL=acid detergent lignin, IVDMD *in vitro* dry matter digestibility, OM=organic matter content, CP = crude protein.

The different constituents in the feeds, and their individual proportions, were used to calculate chemical composition of the feeds for both the control and the browse-fed groups (Table 4.11). The use of bran to support the control group enhanced the crude protein of the feed to 7.69 g/100 g of dry matter and increased the content of minerals and other measures of digestibility and nutrition. The crude protein for the browse-fed lambs was 11.25 g/100 g of dry matter (Table 4. 11).

4.5 GROWTH RATES OF LAMBS

Lambs for the trial were weaned at three months and were fed to the age of six months, i.e. the age at which females are sold as breeding stock to other farmers. The control group was fed sorghum bran. The results of the trial are summarised in Table 4.12. Figure 4.28 shows the mass gains over the 134 days of the trial, including the first 14 days of adjustment to the feed. The final data were collected after the lambs were vaccinated at 120 days, prior to release to farm management. Data collected at the time of the release of the lambs at 134 days are included. It is noted that in trials of this kind the commonly used number of days are 60 and 120

(Aganga and Monyatsiwa, 1999; Beerman *et al*., 1986; Macit *et al*., 2001; Said and Tolera, 1993; Shenkoru and Mekonnen, 1994.

Table 4.12 Response of lambs to feeds in the trial

	Control / Bran+grass	Browse + Grass	T-value
Initial mass (kg)	16.00 ± 0.79	16.04 ± 0.53	0.9691
Final mass (kg)	27.72 ± 1.58	29.75 ± 0.59	0.1601ns
Metabolic mass ($kg^{0.75}$)	11.90 ± 0.52	12.74 ± 0.19	0.1538ns
Body mass gain (kg)	11.25 ± 1.27	13.71 ± 0.36	0.0836ns
ADG (g/day)	83.95 ± 9.49	102.33 ± 2.70	0.0836ns

The results (Table 4.12) show that both the mean mass gained over the period of the trial and the average daily gain of the browse group were greater than those of the bran group. The metabolic rate was also higher, even though not to a significantly different degree. The mean mass gain per animal over the study trial was 2.03 kg more for the browse-fed lambs compared to the control group. Between day 40 and day 120 there were significant differences between the two groups but as the groups reached maturity mass gain narrowed down and at the time of release on day 134 the difference between the groups was not significant (Fig. 4.28).

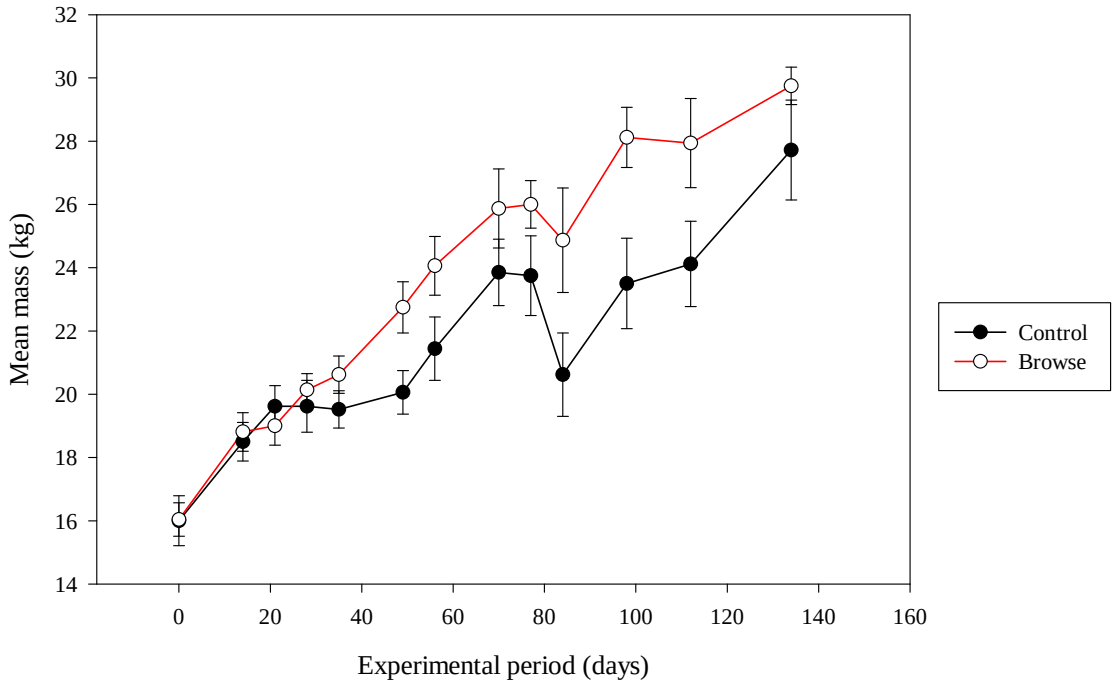


Fig. 4.28 Mean mass of browse and control groups of dorper lambs

N = 8

There was little difference between the two groups in the first 14 days of adjustment to feed. At 21 days the bran group recorded a higher mean mass. By day 49, in the seventh week of the trial, there was a significant difference ($p = 0.0245$) between the mean mass of the browse-fed group and that of the bran-fed group (Appendix 7, Table 1). When data were collected on day 84 it was apparent that the masses were significantly different ($p = 0.0645$), and on day 98 the masses were also significantly different ($p = 0.0174$), as shown in Appendix 7, Table 1.

5.0 DISCUSSION

5.1 GROWTH OF INDIGENOUS TREES

5.1.1 Survival over 6.5 Years

The survival rate of *A. galpinii* was comparable to that of *F. albida*, 99 and 98% respectively, both at the preliminary assessment at the age of 0.5 years and up to the age of 4.5 years. However, gradual dying and falling off of branches of *F. albida* was observed during the dry season of 1997. This dry season was followed by below average rainfall of 372.4 mm in the 1997/1998 season (Appendix 2, Figure 1 and Table 1). High mortality of trees (67%) was recorded for *F. albida* at the end of the dry season in September 1998 while the survival of *A. galpinii* remained at 99% at the completion of the study. The high mortality of *F. albida* in this study is consistent with that experienced by other researchers (Harmand and Njiti, 1992; Vandenbeldt, 1992; Wanyancha *et al*., 1994), in Mouda Cameroon, Niamey, Niger, and Matopo, Zimbabwe, respectively.

In this study high mortality of trees could not be correlated with either spacing or location within the trial plots, as observed in the studies of other researchers (Harmand and Njiti, 1992 Vandenbeldt, 1992) who found that soil depth influenced growth and that growth was better on old termite mounds. Wanyancha *et al*. (1994) ascribed poor survival and growth of *F. albida* to the shallow soil of Matopo, Zimbabwe. Soil analyses conducted at Sebele Research Station (Appendix 3), show that soil in the current study was generally poor in organic matter and excessively well drained. The water table at the site is at a depth of approximately 45 m and generally boreholes in the surrounding area vary in depth from 60 – 120 m (Department of Water Affairs and borehole depth at the trial site).

In their study, Roupsard *et al*. (1999) found that in Sudanese West Africa *F. albida* roots were distributed through the weathered rock down to the water table at 7 m and that the sap contained a similar concentration of the hydrogen isotope, tritium, as the groundwater. They ascribed the survival of *F. albida* in the dry season to its ability to tap groundwater and to reduce its

transpiration. This reliance of *F. albida* on underground water would seem not to have been possible under the environment of Malotwana where the water table is very low. Other studies (Fagg, 1992; Wood, 1989, 1992) suggest that the species is commonly found in alluvial soils along watercourses where the water table is generally high. In this respect the results suggest that, while the species may be drought-resistant, it is an obligate phreatophyte requiring a relatively high water table to enable it to survive, as reported by Roupsard *et al.* (1999). This suggests that in Botswana trials will need to be focussed in areas that have deep soils and a high water table. Consequently areas where the species occurs in fields and is well distributed should be the focus of future research. Such areas could include Tati East in the north and Tutume sub-district.

The survival percentage of *A. galpinii* was high at 99% and was maintained throughout the study period. The high survival and good growth of the species suggest that although it originates along watercourses it can be planted in a wide range of sites. The results indicate that *A. galpinii* has a greater ability than *F. albida* to adapt to sites other than that of its origin. In the species elimination trials of FAB (Kooiman, 1992), the survival of *A. galpinii* over three years was good in the Shoshong and Serowe sites where the species is indigenous. In contrast, at Pelotshetlha where the species was introduced, survival was only 43% after three years (Kooiman, 1992). Soils at Pelotshetlha, although deep, have impeded drainage (Table 2.1 from Kooiman, 1992) which may suggest that, based on the results of this study and those at Shoshong and Serowe, *A. galpinii* could be recommended for deep, sandy soils. However, caution should be exercised for areas with soils that differ greatly, especially in depth and drainage, from those of the places of origin. This, as with the apparent need to plant *F. albida* in sites closely matching the sources of the species, seems the most important recommendation in promoting indigenous trees within Botswana. The results of the contrast between *A. galpinii* and *F. albida* in this study compare well with the seedling trials of *A. tortilis* and *F. albida* (Stave *et al*., 2005). They found that while *A. tortilis* and *F. albida* were able to elongate roots in response to simulated drought, there was a limit to the extent to which *F. albida* could survive prolonged simulated drought. In contrast to *F. albida*, *A. galpinii* has been able to thrive despite poor rainfall at Malotwana showing an ability to thrive both under good rainfall and in years of drought as *A. tortilis* in simulated drought in their study.

F. albida measurements were continued following the regeneration of the species after the good wet season of 1998/1999 (Appendix 2, Figure 1). The 1998/1999 wet season (September to May) had a total rainfall of 445.2 mm which led to regeneration from roots (Plate 4), and the high total of 728.1 mm in the 1999/2000 rainfall year led to high growth of coppice shoots growth suggesting that at least 60% of the trees had survived both drought and possible termite attack, either completely or in part.. As shown in Appendix 4, Table 1, the n-value was 70% in high density plots and 65% in low and medium density stands. Consequently plant population and competition for resources could not explain the high tree mortality of *F. albida*. Regeneration was more vigorous in the low density plots where competition for moisture was probably not as great as in high density stands. Similarly, mortality of trees could not be ascribed to weed management through ploughing since resprouting was close to where the main stem would have been, rather than away from the main stem which would have been the case under vegetative roots which had been cut.

5.1.2 Crown Width

At 0.5 years crown width did not differ significantly between species, as shown in Figure 4.1 ($p = 0.2515$). However, in all subsequent measurements *A. galpinii* exceeded *F. albida* in crown width. The highly significant difference between the two species ($p<0.0001$) throughout the study period could be ascribed to two main factors. Firstly, it can be attributed to the multi-stem nature of *A. galpinii* (mean = 2.35) compared to the more commonly single-stemmed *F. albida* (mean = 1.35) (Appendix 4, Table 1). However, the major factor which contributed to significant differences was the dieback and breaking off of branches, leading to reduced crown width of *F. albida*.

The growth in crown width for both species was not significantly affected by planting density in the first 4.5 years of growth, possibly because competition for resources had not yet occurred as the spacing was wide. However, at the age of 2.5 years species x spacing interaction was significant ($p = 0.0452$), suggesting that the growth of the two species was not at a similar rate and therefore spacing affected the two species differently at different ages. For *A. galpinii*

crown width was greatest in the medium density plots, while with *F. albida* the mean value was highest in high density stands (Figs. 4.2 and 4.3). The *F. albida* mean does not seem logical, as one would expect crown width to be greater in either the low density plots or medium density plantings, taking advantage of the space available to branch. With *A. galpinii* the greatest crown width was in the medium density plots at the age of 2.5 years.

At the age of 6.5 years, analysis of variance (Appendix 4, Table 2) shows there were significant differences among tree stands ($p = 0.0406$). Mean tree crown width in low density plots was significantly greater than those of both medium and high density stands. In both species, plants in low density plots appeared to have taken advantage of the space available to expand crown width. Competition for light may also have caused plants at high density to limit crown spread and grow more vertically. The results, especially with regard to *A. galpinii*, suggest that the species will require different planting densities for different purposes. In silvopastoral situations, where shade for animals and understorey planting is important, even wider spacing than 8.3 x 5 m in this study may be preferable in Botswana, because a single tree may be adequate to reduce evaporation from the upper soil layers for understorey crops, while providing shade. The tree will offer only limited competition for nutrients and water, because of the different depths of root systems of the tree and the understorey crop.

Future evaluation of *A. galpinii* for silvopastoral planting should include intercropping with grass or other fodder plants in the different stands. This should determine the appropriate density for the species on-farm which maximises biomass for fodder. For the objectives outlined, the results suggest that *A. galpinii* takes advantage of space to spread its crown and is effective in providing shade for livestock.

The regeneration of the surviving *F. albida* trees in 1999/2000 was vigorous, and possibly favoured by a well established root system so that the mean crown width exceeded 2 m in all spacings (Fig. 4.3 and Appendix 4, Table 1). In the light of the regeneration that occurred, further research on more selective sites needs to be carried out before the species is discounted.

The development of crown width during the growth of both *A. galpinii* and *F. albida* species is not reported widely in literature. However, the *A. galpinii* mean crown width of 6.08 ± 0.14 m achieved at the age of 6.5 years compares well with those of both *Acacia tortilis* and *Prosopis cineraria* in the Thar Desert of India under similar rainfall conditions with a mean annual rainfall of 489.7 mm (Saini and Yadav, 1989). In their study evaluating an eight year old stand, they recorded crown width means of 9.3 and 5.6 m in *A. tortilis* and *P. cineraria* respectively. *A. tortilis* has more stems than *A. galpinii* in natural stands in Botswana (personal observation) and can therefore be expected to have a wider crown width than *A. galpinii*.

5.1.3 Height

At the first measurement, when trees were 0.5 years old, the mean tree height of *A. galpinii* was greater than that of *F. albida,* 1.53 ± 0.006 and 1.24 ± 0.006 m respectively (Appendix 4, Table 1). Between the ages of 2.5 and 4.5 years, *F. albida* gained 1.81 m in height compared to 1.44 m for *A. galpinii*. This suggests *A. galpinii* grew faster in the first 2.5 years and is consistent with its early growth observed in nursery studies (Motoma, 1998; Tietema *et al.*, 1992). The results also suggest that, once established, height growth may slow down when stem diameter becomes well developed, although this could be a response to adverse moisture conditions. In contrast to *A. galpinii*, in the first year the growth of *F. albida* was slow while in subsequent years the height increment was greater (Fig. 4.4). This is consistent with the observations of Okorio and Maghembe (1994) that *F. albida* grew slowly initially but growth accelerated once established. There was a progressive reduction in height increment in *A. galpinii* between the three biennial measurements of 1.44, 1.03 and 0.9 m, between 0.5 to 2.5, 2.5 to 4.5 and 4.5 to 6.5 years of age respectively. Rainfall totals between the two growth periods may have influenced height gain. The mean annual height increment of *A. galpinii* was, however, 0.82 m over four years which is within the range of acceptable height gain of 0.7-1.2 m of *F. albida,* as documented by Wanyancha *et al.* (1994). In that respect it can be suggested that this species possesses great potential.

The difference in height between the two species was significant, with p-values of $p = 0.0006$, $p<0.0001$, $p = 0.0113$ and $p<0.0001$ at the ages of 0.5, 2.5, 4.5 and 6.5 years respectively (Fig. 4.4). In all data collections, except at the age 4.5 years, *A. galpinii* was significantly greater in height than *F. albida*. Once watering was stopped at the end of the dry season of 1994, rainfall appears to have been influential in the performance of the two species. The height increment of *A. galpinii* was reduced only marginally, while *F. albida* gained greater height initially, but over extended drought conditions dieback and subsequent high mortality resulted.

Heights attained by *A. galpinii* (Fig. 4.5) at all three densities were superior to those of Shoshong, Serowe and Pelotshetlha, both five months after planting and at the age of three years as reported by Kooiman (1992). However, Kooiman's report (1992) did not interpret the data to indicate that measurements five months after planting were based on growth between February and July, when trees did not have the benefit of a complete wet season (Appendix 2, Fig. 1). Any post-planting increase in height would have been limited by dry conditions. However, there would appear to have been little gain in height between the data collection five months after planting and data collected at the age of three years by Kooiman (1992). The difference is not explained in his technical report, but may be lower than that of this study due to differences in management.

A. galpinii at different spacings in this study is contrasted with the performance of *F. albida* in Mafigo, Tanzania (Okorio and Maghembe, 1994) at different planting densities over the study period of 6.5 and 7 years respectively (Fig. 5.1). The planting densities for their study were 4 x 4, 5 x 5 and 6 x 6 m in contrast to 5 x 5, 6.3 x 5 and 8.3 x 5 m for this study. Annual rainfall ranged between 600 and 1000 mm over seven years. The first data collection was ten months after planting, in contrast to six months in this study. However, the trend in growth was similar to that observed in this study, even though mean tree heights were greater in their study, possibly because of higher rainfall and better soil conditions, with a pH of 6.5 at Mafigo, Tanzania. This is in contrast to seasonal rainfall (i.e. between September and May) ranging between 372 and 728 mm and a pH of 4.4 at the Malotwana study site. With *A. galpinii* there were no significant differences among the means of trees in contrasting stands which is consistent with the findings of Okorio and Maghembe (1994) in their *F. albida* study. This suggests that there were few

variations in soil conditions at the Malotwana site, which is consistent with the soil analysis for the trial site which indicated fairly uniform levels of low fertility.

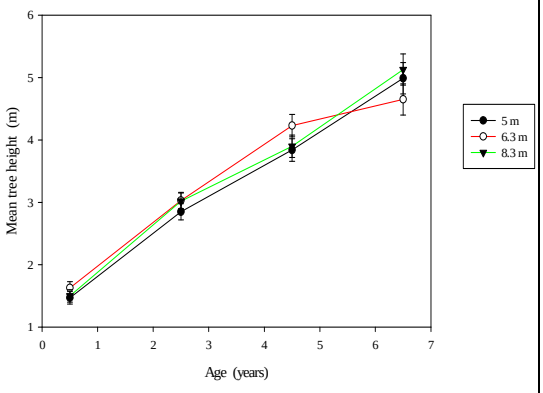
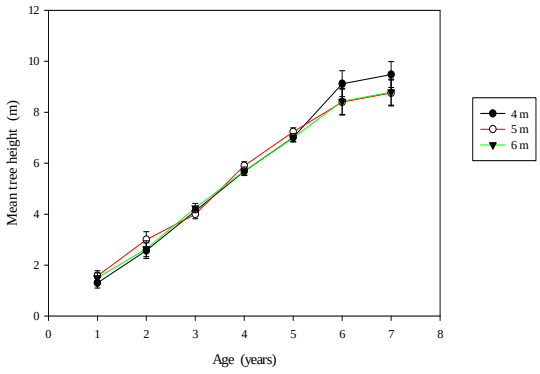


Fig. 4.5 Mean tree height of A. galpinii *at different spacings*



Mean tree height of F. albida *at different spacings (Okario and Maghembe, 1994)*

Fig. 5.1 Comparison of mean tree height at different spacings A. galpinii and F. albida

The comparable growth of *F. albida* in Okorio and Maghembe (1994) to that of *A. galpinii* in this study could suggest that in an area where conditions are not conducive to *F. albida*, planting of *A. galpinii* could yield equally good results to those of *F. albida* in preferred sites. On the other hand, *F. albida* appears to require either much higher rainfall and better soil conditions, as suggested by Vandenbeldt (1992), or a high water table (Roupsard *et al*., 1999). In this regard, although further research may still be needed, *A. galpinii* can be recommended for planting in northern and eastern Botswana, where soils are deep and well drained. In contrast *F. albida* may require more specific sites to be identified if plantings are to be successful.

The growth of *F. albida*, with mean heights of 1.24 + 0.05 m achieved at the age of 0.5 years (Fig. 4.6), was superior to that of the 0.7 m recorded in Tabora, Tanzania, by Karachi *et al*. (1997). However, Karachi *et al*. (1997) did not provide information on the heights of the seedlings at planting. At the age of 2.5 years in their study, the mean height accorded with that of 2.5 m in this study. Wanyancha *et al.* (1994) suggested that a mean height gain per annum of 0.7 to 1.2 m is considered reasonable for *F. albida.* The average annual height growth of 1.22 m for *F. albida* until curbed by the drought was promising. Data collected up to that stage could mislead researchers into recommending the species for planting in eastern Botswana. Given that

the pattern of rainfall over the seven years of this study is similar to long term trends recorded by the Botswana Meteorological Department (Mmopi, personal communication), a lengthy trial period seems essential if valid recommendations of the species to farmers are to be justified.

As Figure 4.6 shows, the heights achieved by regrowth of *F. albida* at the end of the wet season of 1999/2000 were greater than those of measurements at 0.5 and 2.5 years, probably because of the well developed root system of the stumps. Low density plot means were significantly greater than those of high density stands, possibly because of less root competition for soil moisture and nutrients. However, also of significance was the fact that rainfall totals (Appendix 2, Table 1) received in the two seasons were 445 mm in 1998/1999 and 728.1 mm in 1999/2000, the latter being well above the long term mean.

That there were no significant differences in tree mean height values at different densities in this study accords with the findings of Okorio and Maghembe (1994). This suggests that site conditions did not vary within plots. Their measured heights were greater than those recorded in this study, possibly because of better soil nutrition, especially the pH of 6.5 which facilitates nutrient uptake, compared with pH 5.2 in this study. However, the slower growth in this study compared with theirs could be ascribed to the much lower growing season rainfall at Malotwana which was highly variable over the seven years. It ranged from as low as 372 mm to a maximum of 728 mm during the period of the study, compared to annual totals of between 600 and 1000 mm at Mafigo, Tanzania, and an annual mean of 800 mm at Ouagadougou, Burkina Faso (Billand, 1992).

Mean tree heights of *F. albida* achieved in these results are comparable with those of the best performing provenances in the study of Vandenbeldt (1992) in sandy soils at Sadore, Niger. His results varied according to provenance. At the age of four years the trees in his study had a mean height of 4 m compared to mean heights of 4.99 m at the age of 4.5 years at Malotwana, Botswana.

5.1.4 Diameter at Breast Height

Throughout the study, mean tree dbh of *A. galpinii* (Fig. 4.7) was significantly greater than that of *F. albida*, ($p = 0.0283$, $p = 0.0001$ and $p = 0.0001$ at the ages of 2.5, 4.5 and 6.5 years respectively). The results showed a much better performance by the less known *A. galpinii* compared to *F. albida.* Rainfall did not have much influence on the performance of *A. galpinii*, the dbh increment being 3.5 cm at both intervals of data collection, between 2.5 and 4.5 and 4.5 and 6.5 years. This was despite very low rainfall in the season before the measurement of trees at the age of 4.5 years. Apparently diameter growth is less affected by drought than height growth. This may be attributed to the good growth following the high rainfall of the 1995/1996 season, even though slow growth might have occurred in the drier season of 1996/1997. Annual data collection, which better shows the annual increment, may need to be carried out in future research to show the annual gain of diameter at breast height. As with crown width and height, values of *F. albida* are lower due to the fact that data collected were from trees that had resprouted.

For *F. albida* the 2.5 cm gain was immediately followed by high tree mortality during the drought conditions of 1997/1998. Consequently measurements of diameter at the age of 6.5 years for *F. albida* were lower, with a value of 4.31 cm, as opposed to the diameter of 5.93 cm (Fig. 4.9) at the age of 4.5 years, at which age the dbh of *A. galpinii* was 11.14 ± 0.37 cm. Rainfall variations (Appendix 2, Fig. 1) affected *F. albida* drastically, but had a limited impact on *A. galpinii.*

Figure 5.2 compares the dbh gain of *A. galpinii* at different spacings in this study (Fig. 4.10) with that of *F. albida* grown at Mafigo, Tanzania, from the study of Okorio and Maghembe (1994). The three plot densities of the two studies differ as indicated in Section 5.1.3, however, the trend in the effect of spacing on dbh increment was similar.

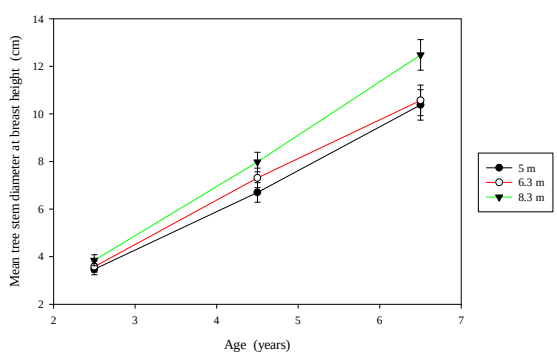
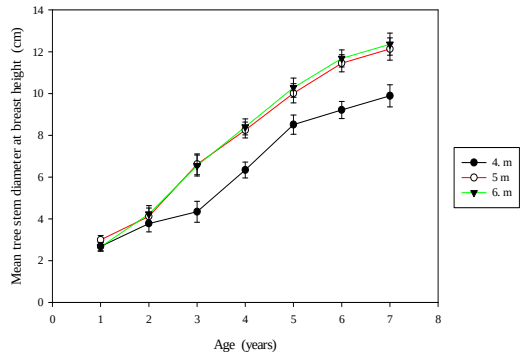


Fig. 4.8 Mean tree stem diameter at breast height of A. galpinii *at different spacings*



Mean tree stem dbh of F. albida *at different spacings (Okorio and Maghembe,1994)*

Fig. 5.2 Comparison of mean dbh at different spacings A. galpinii *and* F. albida

The mean tree dbh of low density plots was greater than those of both the medium and high density spacings of *A. galpinii* in this study. Likewise, in the study of Okorio and Maghembe (1994) there were significant differences ($p<0.05$) and the mean of trees at low density was significantly greater than that of the highest density stands. In their study significant differences between means were recorded in the third year from planting, possibly because the stands had closer spacing than those in this study. In this study highly significant differences were only recorded at the age of 6.5 years ($p = 0.0003$), possibly because the spacing selected was much wider than that of Okorio and Maghembe (1994). However, the effect of spacing on diameter growth was becoming apparent at the age of 4.5 years, as signified by a low P-value ($p = 0.0567$). The significantly lower dbh value in high density plots can be ascribed to higher competition for nutrients leading to thinner stems compared to in low density stands where plant competition would have taken longer to be exerted.

The importance of these results is that in agroforestry plantings *A. galpinii* can be selected for different products, depending on end-use, such as the carving of traditional tools which can readily utilise the wood produced. Mortars could be carved from trees with wider spacings while pestles and poles for building and fencing could be harvested from medium and high density stands. For all uses woodfuel could be a by-product. Of particular importance is the fact that *A.*

galpinii reached a dbh of 10.38 to 12.48 cm, at 6.5 years, which is comparable to that of *F. albida* in the study of Okorio and Maghembe (1994), with values of 9.89 and 12.36 cm in high and low density plots respectively at 6 years. This suggests that *A. galpinii* plantings should be encouraged for agroforestry in eastern Botswana in preference to *F. albida,* especially as the latter appears to have limited areas where it can thrive. For other uses, such as pole production and fuelwood, *A. galpinii* has great potential at close spacing and is highly productive because of its multi-stem nature.

Although the pattern of growth of *F. albida* was affected by high mortality, the trend for the first 4.5 years shows a greater mean dbh in low than in high density plots (Fig. 4.9). This is consistent with the findings of both Harmand and Njiti (1992) and Okorio and Maghembe (1994) in Mouda, Cameroon, and Mafigo, Tanzania, respectively. In both studies the performance of the species showed significantly greater diameters at breast height at six years in trees planted in low density plots compared to those of high density stands. However, as already indicated in the discussion of both crown width and height increment, values of *F. albida* were affected by high plant mortality after the measurements taken 4.5 years after planting. These resulted in dbh values ranging between 1.99 ± 0.78 cm in high density stands and 6.05 ± 0.83 cm in low density plots at 6.5 years.

With regard to *F. albida* the results are very disappointing, as was the case in Matopo, Zimbabwe (Wanyancha *et al*., 1994). Other places research sites where the species has not performed well include Moundo, Cameroon, and Niamey, Niger (Harmand and Njiti 1992; Vandenbeldt, 1992). Of significance for those who have been in extension for many years, the results point to the poor link between research and the promotion of species. This may be true of Botswana rather than being universal. From the reviews of Cisse and Kone, (1992); and Vandenbeldt (992) it is clear that establishing *F. albida* in trials has been a subject of discussion for some time and poor performance of the species has been known among the researchers involved in “range-wide provenance trials” for much longer. Reservations about the species appear not to have filtered down to those involved in forestry extension in Botswana which may be true of other countries. However, as indicated by the results of areas such as Morogoro

Tanzania (Okorio and Maghembe 1994), the species appears to do well only in areas that possess specific favourable site characteristic that suit to the species (Vandenbeldt, 1992).

5.1.5 Stem Volume Index

Figure 4.10 shows the contrast between mean tree stem volume index in the two species. The two species differed in growth from the first measurement at the age of 2.5 years, with *A. galpinii* showing superior early establishment. This was influenced by its multi-stem nature compared to *F. albida*. The effect of drought conditions, with a total of only 372.6 mm in the 1997/1998 season, further exacerbated the difference between the two species. There were significant differences at all stages: $p<0.0001$ at all ages (2.5, 4.5 and 6.5 years).

Species x spacing interaction was not significant in any of the years of data collection (Appendix 4, Table 5). However, the value of $p = 0.0613$ at 6.5 years suggests that over time greater differences between the species could be expected, both in terms of the spacing used and the location of planting.

5.1.6 Flowering and Pod Production

Over the 6.5 year period of the study, both tree species continued to retain leaves throughout the year. Although this is contrary to the commonly reported phenology of *F. albida,* and what is observed at all sites where seed is collected in Botswana. However, van Wyk and van Wyk, (1999).suggest that the retention of leaves throughout the year is characteristic of the species in Namibia.

There is considerable variation in the expected age of first flowering, with 8, 12 or 15 years suggested by different researchers (Cisse and Kone, 1992). No flowering was observed during the period of research in either *A. galpinii* or *F. albida.*

The site therefore provides an opportunity for the further research needed to clarify the potential contribution of the two species for fodder production. This is particularly important in the long

term, especially as the pods, may offer greater potential for dry season feed than the leaves, which are small and not easy to harvest. Little information is available on the production of pods by *A. galpinii* due to the minimal research so far conducted for agroforestry planting. However, as with *F. albida*, no podding occurred during the 6.5 year study period. Planted *A. galpinii* trees have been observed to pod after nine years along the Sir Seretse Khama Airport road near Gaborone in Botswana. Farmers in Botswana could pursue growing of *A. galpinii* as it seems to perform well in on-farm plantings, as it has done in the Around-the-Home Tree Plantings of the FAB programme since 1989. In contrast, *F. albida* plantings on-farm have not proved as promising as the individual household plantings. It seems probable that low rainfall and the considerable depth of the water table preclude successful planting in most of Botswana. The species is too problematic to recommend for on-farm planting by farmers until specific areas have been identified through research in selected locations. This may involve concentrating research and on-farm planting in riverside sites such as Tati East in north eastern Botswana, where the species is indigenous. Additionally the riparian areas around Gaborone, where woodland had been depleted, and trees were planted in 1989 under the Around-the-Home Tree Planting programme of FAB have shown promise.

5.1.7 Relationships between Measured Parameters

Correlation between crown width and stem number of *A. galpinii* was not significant until trees were aged 6.5 years (r = 0.336). This could be because initially the influence of stem number to crown width is not apparent as the tree is still mainly growing in height. In contrast with *F. albida* the correlation was significant at the age of 4.5 years but negative (r = - 0.036) (Table 4.1). There was a positive and increased r-value at 6.5 years. However, this was probably associated with the fact that the bushy resprouting resulted in wider crowns giving a misleading result between crown width and stem numbers (r = 0.651). From the 1996 and 1998, data notwithstanding the dieback and mortality, in the latter year, it would appear that there is a very weak link between crown width and stem number until trees are well established. This is evident, with *A. galpinii*, which was successfully grown having a significant, but not high, value at 6.5 years.

For *A. galpinii* there was a strong correlation between crown width and diameter at breast height which increased with age (r = 0.692 and r = 0.722 at 2.5 and 6.5 years respectively). These results were similar to those of *F. albida* where the r-values were highly significant at the ages of 2.5, 4.5 and 6.5 years, the correlation coefficients being r = 0.613, 0.656 and 0.816 respectively.

In both species the high correlation coefficient between crown width and dbh could provide an opportunity to estimate biomass production from the easily measured parameter of dbh instead of applying destructive sampling. However, further research is needed to relate crown width more accurately to dbh, as well as with the agroforestry products such as pods.

The close negative relationship between stem number and dbh is to be expected, as a higher stem number per tree might suggest thinner stems will develop because the root system remains the same. With *A. galpinii* the number of stems per tree was positively related to height 6.5 years from planting (r = 0.264). The initial negative relationship could be explained by the fact that the central shoot is not readily defined in early growth, while, as trees develop, a dominant stem becomes apparent and may also be influenced by spacing to grow upright into the principal shoot. This is likely with widely spaced trees as in this study and especially during early growth.

The correlation coefficients show a positive association between crown widths and stem volume index in both species. This suggests the possibility of using crown width as an estimate of biomass production for both species.

Diameter at breast height was positively correlated with tree height, with r-values of 0.255, 0.987 and 0.707 at 2.5, 4.5 and 6.5 years respectively. Much more data need to be collected to relate dbh with height for *A. galpinii* at different densities. A high correlation could be expected, if competition for soil moisture and nutrients amongst measured trees is similar, as both height and dbh are influenced by site quality and genetics (van Laar, 1991). Therefore, dbh could be used to predict height to facilitate harvesting for poles.

5.2 GROWTH OF EXOTIC TREES

5.2.1 Survival over 6.5 Years

The respective survival rates were 87 and 97% for *L. diversifolia* and *L. leucocephala.* Over the period of three years of their studies, Karachi *et al*. (1997), Kooiman (1992) and Ty (1998) in Tanzania, Selebi-Phikwe in Botswana, and Vietnam respectively, reported a similarly high percentage survival. It is not surprising that survival rates reported by Kooiman (1992) were similar to those of Malotwana, as the rainfall of the site is similar to that of Malotwana, as are the soil conditions, both characterised by low fertility (Table 2.1 and Appendix 3). Similarly, watering was employed in the FAB trial up to 18 months after planting (Kooiman 1992) in line with the practice in Eucalyptus plantations in Botswana. Neither Karachi *et al.* (1997) nor Ty (1998) reported watering, but rainfall totals in their research sites were higher than that of this study. This suggests that growing the two species is possible, even in the dry conditions and acidic soils of Botswana, which just fall within the lower limit of pH 4.8 (KCl) suggested by Ty (1998) who conducted research on *Leucaena* species in a wide range of sites under varying degrees of acidity.

The use of irrigation over 18 months by Kooiman (1992), together with the ripping and ridging which improve water infiltration at least initially, may explain the 100% survival in Selibi-Phikwe FAB trials. However, it is unlikely that trees will survive in Botswana without initial watering. Similarly, it is worth noting that most fodder plant species, such as *Medicago sativa* and *Lablab purpureus*, are produced under irrigation with potable or treated sewage water so that fodder trees, such as *Leucaena diversifolia* and *L. leucocephala*, will not be unique in requiring watering. With these survival rates the species can contribute to Botswana's fodder production in poor soil and with a marginal pH of 4.2 ($CaCl_2$). There was, however, considerable variation in coppice growth in different years, which suggested that watering at critical times may be necessary. This should be an aspect of future research, as should the yield of tree fodder compared to that of commonly used fodder plants. Consequently any research solution for fodder should involve several species used for feed in Botswana such as *M. sativa* and *L.*

purpureus. These should be subject to the same water management and their productivity compared to that of different leguminous trees.

The performance of trees throughout the 6.5 years of the study for various parameters is presented in Figures 4.13 to 4.27. A complete plant harvest was carried out for the first time at the age of 2.5 years and subsequently after each coppice shoot growth over 2 years, until the final harvesting 6.5 years after planting. Due to the deciduous nature of the species, leaf and pod yields at each complete plant harvest were for the rainy season ending in May each year.

5.2.2 Crown Width

At 0.5 years there were differences between the species ($p = 0.0577$) with *L. leucocephala* having a greater crown width, probably due to the larger number of stems influencing the results (Appendix 5, Table 1). After the first complete plant harvest at 2.5 years, mean crown width from coppice regeneration at the end of the wet season one year after harvest, exceeded 2 m (Fig. 4.13) and was greater than in the first 1.5 years. This could be ascribed to more shoots creating a wider crown by extending from the stumps, especially with vigorous plants aided by an established root system. However, after the second harvest the mean crown width was lower than that one year after the first harvest. This could first be ascribed the fact that the 1997/1998 rainfall, prior to the harvest, was poor (Appendix 2, Table 1) and could explain the limited plant growth. Subsequently the 1998/1999 rainfall was better and was followed by very good rains in 1999/2000, enhancing tree growth. The superior crown width of *L. leucocephala* compared to *L. diversifolia* could be associated with its greater number of coppice shoots (Fig. 4.22).

Mean tree crown width, although greater in *L. leucocephala*, was not significantly different between the species except at the age of 5.5 years when the difference was statistically significant ($p = 0.0443$). The year prior to this data collection was very dry 1997/1998 and the significant result may be explained by the fact that following such a drought year *L. leucocephala* responded much more readily in coppice regrowth to the good rainfall of 1998/1999 than *L. diversifolia*. Karachi and Lefofe (1997) observed that a cold and virtually rainless winter season affects *L. diversifolia* and *L. leucocephala*, both species dying back in

winter, although they readily regenerate in the wet season. This contrasts with the findings in this study where *L. leucocephala* appeared to respond much more quickly**.**

The mean tree crown width was significantly different among planting densities at the ages of 3.5 and 4.5 years (p = 0.0357 and 0.0396 respectively). Trees of both species in low density plots had significantly greater means than those at both medium and low density plantings at this early stage. This may be ascribed to the fact that trees at wider spacings had less competition for soil nutrients than trees growing closer to each other, especially as rainfall was poor prior to the data collection at 4.5 years. Complete harvesting 4.5 years after planting was followed by two years of good rainfall. During those years, at the age of 5.5 and 6.5 years, spacing did not affect crown width significantly (p = 0.3947 and p = 0.3344 respectively), possibly because availability of soil water in the densest plots was no longer inhibiting tree growth.

Although growth in crown width did not differ among spacings at the age of 5.5 years, species spacing interaction was statistically significant (p = 0.0353) and the p- value was low when trees were aged 6.5 years (p = 0.0738). The growth of coppice shoots at the age of 5.5 years suggests that spacing influenced the growth of *L. diversifolia* differently from that of *L. leucocephala.* The former's mean crown width was greatest in the low density plots, while for the latter crown width was greatest at medium density. The results indicate that while regeneration of *L. diversifolia* was consistently best in low density stands, for the better-performing *L. leucocephala* both growth and regeneration were superior in medium density stands. The consistently good performance of *L. leucocephala* in medium density plots suggests that for similar conditions, the species should be recommended for planting at this spacing in silvopastoral plantings. This would yield good results for low rainfall years and be beneficial even in wet years.

5.2.3 Height

The growth in height was comparable between species except at the age of 5.5 years after planting when *L leucocephala* had significantly greater mean height than *L. diversifolia* (Fig. 4.16) (p = 0.0002). This period followed the second harvest of trees and, although prior to

assessment the 1998/1999 rainfall was good, the preceding season in 1997/1998 was one of severe drought. The results could be due to the fact that *L. diversifolia* displayed a slower response following prolonged drought than *L. leucocephala*. A year later *L. diversifolia* had responded well to the good rains with the result that at the age of 6.5 years the difference between the two species was no longer significant. As *L. diversifolia* is apparently not as tolerant to drought, it might be considered for planting in areas such as the Chobe District in northern Botswana where rainfall is higher.

At the age of 0.5 years the mean tree height of one metre for both *L. diversifolia and L. leucocephala* was comparable to those of studies conducted in Botswana (Kooiman, 1992) and to the growth recorded at Tumbi, Tanzania, (Karachi *et al*., 1997). The initial mean height at planting at Tumbi was 1.2 ± 0.2 m. At the age of 2.5 years, Karachi *et al*., (1997) reported heights of 4.9 m compared to 3.33 ± 0.07 m for trees planted at a height of 0.40 m. It is, however, noted that although there was no watering for establishment carried out at Tumbi, the annual rainfall is much higher (ranging from 780 mm to as high as 1080 mm). In much wetter areas, and with soils of higher pH values, annual increases in height of between two and three metres have been reported (Shelton and Brewbaker, 1994; Ty, 1998). This suggests that the lower values of this study, compared to those of Karachi *et al*. (1997), could be ascribed to the poor soil conditions at Malotwana and the lower mean annual rainfall than at Tumbi. The Vietnam study (Ty, 1998) showed great variations in height between areas with poor soils and those falling within the recommended range of acidity of pH 4.8 (KCl) or higher; this may partly explain the lower values in this study compared to those quoted in the literature.

Throughout the study, height growth was not influenced by planting density. Species x spacing interaction was significant at the age of 5.5 years ($p = 0.0496$) following the second harvest. *L. diversifolia* means were greatest at low density while for *L. leucocephala* medium density plantings had the highest mean. Maghembe *et al*. (1986) recorded significantly greater mean heights in low density plots of *L. leucocephala* aged four years. In their trial, low density trees were at a spacing of 6 x 6 m, which is similar to the medium density in this study, while their medium density was 5 x 5 and high density 4 x 4 m. There is a need for research on the spacing of both species to ascertain the highest productivity. This is because at the age of 6.5 years the

p-value for spacing was low (p = 0.0656) while the species spacing interaction was 0.1165. Whereas this suggests that with good rainfall *L. diversifolia* could be as productive as *L. leucocephala*, any recommendation in Botswana should be based on the worst conditions scenario for sustainable agroforestry practices to be achieved. On that basis on-farm planting in Botswana could confidently be pursued within three spacings, possibly ranging between 5 x 5 and 8 x 8 m plot densities.

5.2.4 Stem Diameter at 50 cm

Comparison of mean stem diameter between *L. diversifolia* and *L. leucocephala* is shown in Figure 4.19. Growth in diameter declined after each harvest, with lower values for each year of regeneration. This could be explained by the fact that the number of stems per stump increased (Figure 4.22 and Appendix 5, Table 1) after every harvest. However, poor plant growth could also be attributed to the low rainfall of the preceding season of 1997/1998 (Appendix 2, Table 1). This suggestion is reinforced by the fact that subsequent good rainfall of 1998/1999 led to a substantial gain in stem diameter. *L. diversifolia* had superior diameter for most of the study period, except at 5.5 years when diameter values were comparable between the species.

Mean stem diameter at contrasting spacings is presented in Figures 4.20 and 4.21 for *L. diversifolia* and *L. leucocephala* respectively. With *L. diversifolia* diameter was greatest at low density plantings at 3.5, 5.5 and 6.5 years. More consistently the high density plots had the lowest diameter at all measurements. Therefore, where wood is important as an agroforestry product, the widest spacing of 8.3 metres is best for *L. diversifolia.*

L. leucocephala at low density had comparable stem diameter to that of the medium density plantings at 2.5, 3.5 and 6.5 years (Fig. 4.21). As with *L. diversifolia*, the high density plots had the lowest mean values which can, in both cases, be explained by greater competition between plants.

The influence of spacing on the stem diameter of *L. lecucocephala* is reported by Maghembe *et al.* (1986), who found that low density plots produced larger stem diameters compared to more closely spaced trees. This interpretation can also be applied to *L. diversifolia* where lack of

competition between trees at low density allowed bigger stems to develop. In the study of Maghembe *et al*. (1986), tree density was much closer than in this study, with their low density plot being similar to the medium density stand in this research. This may explain why the effect of density at some stages, for example at the ages of 1.5 and at 5.5 years, was not significantly different in this study.

Species x spacing interaction was significant at the ages of 5.5 and 6.5 years. This suggests that the two species require different spacings to attain maximum stem diameter. The stem diameter of *L. diversifolia* was significantly greater in low density stands, with those of medium and high density plots being similar, while for *L. leucocephala* values of high density and low density were comparable and trees at medium density had the highest value at age 5.5 years.

5.2.5 Shoot Numbers

The number of shoots was measured annually, both for initial shoot numbers and for coppice shoots at each data collection. Coppice shoot numbers of the two species are compared in Figure 4.22. Six months after planting *L. lecucocephala* had a mean of 2.05 stems per tree, which was significantly more than the *L. diversifolia* mean of 1.60 stems. Throughout the study, *L. leucocephala* developed more coppice shoots than *L. diversifolia,* but the difference was only significant at 6.5 years, when the mean values were 12.86 vs. 10.41 (Appendix 5, Table 1). However, the p-values of differences in number of coppice shoots between species were low at 2.5 years (0.0858) and 3.5 years (0.0692). An increase in number of coppice shoots after every harvest could be expected as the root system of stumps continued to develop. However, for both species there was virtually no increase in shoot numbers from ages 3.5 to 5.5 years. During this period rainfall was considerably below the average and it is therefore assumed that the limited availability of soil moisture inhibited coppice shoot formation. During and after the good wet seasons of 1998/1999 and 1999/2000 (Appendix 2, Table 1), coppice shoot formation increased substantially (Fig. 4.22). While coppice shoot development was observed in *L. leucocephala* immediately the wet season begins, *L. diversifolia* was slow to resprout.

For both species, plot density had no effect on the number of coppice shoots in the first 4.5 years. However, at age 5.5 years there was significant species x spacing interaction (Appendix 5, Table 5) and the p-value for spacing was 0.0908. As shown in Figure 4.23, for *L. diversifolia* trees aged 5.5 and 6.5 years there were significantly more coppice shoots in low density plots than in trees planted at medium and high density. In contrast, for *L. leucocephala* the differences were much smaller for trees growing at different stands densities (Fig. 4.24). While for *L. diversifolia* root competition increased as the stumps developed over time, especially in the high and medium density plots, with *L. leucocephala* the number of coppice shoots that developed was not significantly affected by density.

Cobbina (1998) reported that in his study in Ibadan, Nigeria (high annual rainfall from 1233 to 1694 mm), with trees planted at densities 20 000, 26 000, 40 000 and 80 000 ha^{-1}, *L. leucocephala* did not take advantage of space to increase the number of stems. This accords with the results of this study and suggests that the lack of variation in the growth between stands of different densities may be consistent with the behaviour of this species. With regard to *L. diversifolia*, the significantly greater number of shoots in the low density plots at 5.5 and 6.5 years may be associated with less competition for moisture and nutrients. Consequently more vigorous growth stimulated the formation of more coppice shoots in the low density trees. Up to 3.5 years, when space was probably not yet fully utilised by trees, plot density had no effect on the number of shoots. However, at 4.5 years the number of shoots in low density plots increased rapidly whereas in the other plots there was a temporary decline in shoot formation. This phenomenon occurred during the period when rainfall was below average and it is therefore postulated that the combined effect of drought and relatively high plot density caused severe stress to the trees in the medium and high density plots and inhibited coppice shoot formation (Fig. 4.23)

The number of coppice shoots produced by *L. leucocephala* was not significantly affected by plot density, except at 1.5 years when medium density plots had a bigger value than low and high density plots, which had similar values (Fig. 4.24). This statistically significant difference cannot be explained because at that relatively young age it is unlikely that conditions that might

favour formation of multiple stems would be present in the medium density but not in low and high density plots.

5.2.6 Stem Volume Index

Throughout the study there were no significant differences between the two species. This may suggest that the bigger stem diameter of *L. diversifolia* compensated for the fewer number of coppice shoots. Over a period of three years in Texas, with annual rainfall totals of 495, 1026 and 682 mm, Gathaara *et al*. (1991) found no differences between *L. leucocephala* and *L. pulverulenta* in terms of total yields in t ha^{-1}.

There were significant differences among planting densities at the age of 3.5 years ($p = 0.0468$), as shown in Appendix 5, Table 6. This was the period following the first harvest and may indicate quicker recovery of trees at low density where there was less competition for moisture. There was also a significant difference among spacings at the age of 6.5 years ($p = 0.0310$). It is would seem that trees at high and medium density with the availability of good moisture competed for nutrients, while the well established low density trees were able to thrive better than those which were closely spaced. Gathaara *et al*. (1991) also found that spacing greatly influenced yields, with low density trees performing best even though their widest spacing was only 3 m.

Species x spacing interaction was not significant at any of the assessment stages.

5.2.7 Agroforestry Production per Tree

5.2.7.1 General

The results of this study are not readily comparable with those of other studies of *L. leucocephala* and *L. diversifolia*, firstly because this study focused on all three major products, leaves, pods and wood, with the consequent harvesting at much later stages of growth, 2.5 years after planting, and thereafter at 2 year intervals. In most of the reviewed literature, harvests were carried out at much more frequent intervals or at the end of wet seasons (Wandera and Njarui, 1998; Wickremasinghe and Gunasena, 1998). A major constraint in making per tree comparisons in this study is that most recent research into *L. leucocephala* has focused either on evaluating production of the *Leucaena* genus under attack by the aphid *Heteropsylla cubana*, or on testing its frost tolerance (Mullen *et al*., 1998). However, both leaf and pod yield can be considered to be annual products from the rainy season, as is true of crop yields in Botswana generally.

5.2.7.2 Mean Tree Leaf Mass

There was a significant difference in leaf mass per tree between *L. diversifolia* and *L. leucocephala* ($p<0.0001$) when trees had grown for 2.5 years. Precipitation for the growing season prior to the harvest was above the average. However, differences in leaf mass per tree were not statistically significant either after a drought year (at the age of 4.5 years) or when rainfall was well above the seasonal mean (at the age of 6.5 years) (Appendix 5, Table 7). When a drought year preceded the harvest, both species had low yields (0.47 and 0.48 kg), whereas after a wet year, both species recorded high yields (2.38 and 2.76 kg) (Table 4.2). The trend for better yields by *L. leucocephala* compared to *L. diversifolia* in this study is comparable to that of Wickremasinghe and Gunasena (1998) in Dodangolla, Sri Lanka, (mean annual rainfall 1563 mm) who obtained mean leaf masses ranging from 0.1 to 0.5 kg per tree for *L. diversifolia* and 0.3 to 0.6 kg for *L. leucocephala* from a two old stand spaced at 1.5 x 1.5 m. However, mean tree leaf masses for both species in the current study were considerably greater, possibly because their research was to test performance of species under psyllid damage but also because the trees

were much more closely spaced (Wickremasinghe and Gunasena, 1998). Karachi and Lefofe (1997) in Morale, Botswana, with annual rainfall of 450 to 500 mm also obtained much lower yields ranging from 0.03 to 0.2 kg per tree from a harvest of trees aged ten months. Their low yield was possibly because trees were not as well established as those of this study. Only one season was evaluated. Ella and Blair (1989) reported greater annual yields in leguminous trees cut at twelve week intervals compared to those cut at six week intervals in Gowa, Indonesia.

There were no significant differences in yields among planting densities, as shown in Appendix 5, Table 7. The only explanation why, on an individual tree basis, low density trees did not consistently yield the highest mean leaf mass (Table 4.2) is that even the closest spacing (5 x 5 m) might have been too wide to effect adequate competition among trees. Species x spacing interaction was not significant.

5.2.7.3 Mean Tree Pod Mass

In most studies, pod yields of *Leucaena* species are not evaluated, possibly due in part to their reported high tannin content compared to the leaves, as confirmed by the results in Tables 4.7 and 4.8. There is widespread appreciation of the need to improve livestock production in semi-arid Africa through increasing the availability of the protein-rich products of fodder trees (Rubanza *et al*., 2003). However, in arid zones such as Botswana, where trees often shed their leaves as a result of drought, it is necessary that both pod yield and quality should be evaluated, as has been done in this study.

L. leucocephala had significantly greater pod mass yield than *L. diversifolia* at all harvests, i.e. at 2.5, 4.5 and 6.5 years. The mean yields were 4.32, 1.44 and 4.43 kg per tree for *L. leucocephala,* while for *L. diversifolia* they were 2.91, 0.72 and 1.79 kg for the respective years (Table 4.2).

In both species mean pod yield of trees aged 6.5 years was significantly greater in trees in at low density plots compared to those planted at both the medium and high density. The mean yield of *L. diversifolia* at low density was 3.58 kg compared to the means of medium and high density trees which were 1.04 and 1.29 kg respectively. Similarly, the mean yield of *L. leucocephala*

was 6.54 kg in the low density stands compared to the similar means of 4.27 and 4.34 kg in the medium and high density plots respectively. These results indicate that once trees were well established, with an extensive root system, there was competition for water and nutrients among closely spaced trees of the medium and high density plots. Species x spacing interactions were not significant throughout the study, suggesting that pod yields were similarly affected by spacing for both species. The relatively high yield of pods, especially of *L. leucocephala*, which constituted between 13.31 and 27.51% of total biomass, and the greater masses of pods than leaves in all years underlines their potential as a source of dry season fodder. The negative effects associated with pod production, such as their high tannin content and the tendency of seeds to be shed at an early stage, are noted. The latter can be mitigated by frequent collection and storage and will also reduce the potential of *L. leucocephala* invading natural vegetation. However, such frequent harvesting will require more labour, which is not readily available to most households. The less weedy *L. diversifolia,* whose pod contribution to total biomass ranged between 6.92 and 23.94%, and whose leaf yields in wet years exceeds that of pods, may be preferred.

5.2.7.4 Mean Tree Wood Mass

Table 4.2, Column 7 shows mean mass of air-dried wood for the two species. There were significant differences between mean wood yield of the two species at the harvests of trees aged 2.5 and 6.5 years ($p = 0.0213$ and $p = 0.0241$), as shown in Appendix 5, Table 9. The mean values were 7.37 kg for *L. diversifolia* and 9.8 kg for *L. leucocephala* at 2.5 years. At 6.5 years the means were 6.68 and 9.46 kg for *L. diversifolia* and *L. leucocephala* respectively (Table 4.2).

Mean tree wood mass was significantly different among planting densities at the ages of 4.5 and 6.5 years ($p = 0.0454$ and $p = 0.0179$). At both ages the trees at low density had significantly greater means than trees at medium and high density. At 4.5 years trees in *L. diversifolia* low density stands had a mean of 11.68 kg, while those at medium and high density had comparable means of 6.67 and 6.25 kg respectively. With *L. leucocephala* this trend was the same, though not so pronounced, with values of 8.36 kg for low density plots compared to 7.99 and 7.27 kg for trees at medium and high density. The harvest of trees aged 4.5 years was followed by a season

of poor rainfall which would suggest that in closely spaced trees moisture competition would have been intense. The effect of this was exhibited by both species at the harvest of 6.5 years. For *L. diversifolia* the low density mean yield, at 10.85 kg, was significantly greater than those of trees at both medium and high density with values of 6.15 and 5.07 kg respectively. For *L. leucocephala* the values were 10.95, 9.98 and 8.95 kg for low, medium and high density plots respectively.

Species x spacing interaction was not significant at any of the harvests (Appendix 5, Table 9).

5.2.7.5 Mean Tree Total Biomass

Total biomass yield per tree is presented in Table 4.2, Column 8. The total biomass yield of *L. leucocephala* was significantly greater than that of *L. diversifolia* at the harvests of trees aged 2.5 and 6.5 years. The values recorded were 18.24 and 17.86 kg for *L. leucocephala,* compared to 12.80 and 11.87 kg for *L. diversifolia* for the harvests of trees aged 2.5, and 6.5 years respectively. *L. leucocephala* had a greater mean total biomass, but not significantly so, in the harvest of trees aged 4.5 which followed after poor rainfall.

Trees at low density produced a significantly greater mean wood mass than those in both high and medium density plots at the ages 4.5 and 6.5 years (Appendix 5, Table 10). At the harvest of 4.5 years the mean of low density *L. diversifolia* trees was 11.66 kg, which was considerably greater than those of trees at medium and high density with values of 7.54 and 6.94 kg respectively. For *L. leucocephala* the mean of low density plots at 10.28 kg, slightly exceeded that of trees at medium density with a value of 10.05 kg. Both were considerably greater than the mean for high density plots of 8.75 kg. In the final harvest of trees aged 6.5 years the low density mean was significantly greater ($p = 0.0302$) than those of both medium and high density stands for both species. With the benefit of the good rains which preceded this final harvest, the yields of both species were much higher in the low density stands where competition for water and nutrients was substantially less than where trees were more closely spaced. For *L. diversifolia* the values were 17.64, 9.43 and 8.54 kg for low, medium and high density plots respectively. Equivalent values for *L. leucocephala* were 20.35, 15.91 and 11.87 kg

respectively. Thus for both species the influence of spacing on total biomass yield is clearly demonstrated.

5.2.8 Agroforestry Production per Hectare

5.2.8.1 Leaf Mass per Hectare

L. leucocephala had significantly greater mean leaf yield per hectare, 1.237 t compared to 0.647 t for *L. diversifolia* at the harvest of trees aged 2.5 years ($p<0.0001$). Spacing significantly influenced yields ($p = 0.0003$) of the two species at this age. This trend, though not significant ($p = 0.0980$), was followed in the yields of trees aged 6.5 years. At the harvest of 2.5 years the mean of trees at high density was 0.902 t ha^{-1} for high density plots of *L. diversifolia* compared to 0.602 t ha^{-1} in medium density plantings, which, in turn, was significantly greater than the value of 0.438 t ha^{-1} for low density plots. The *L. leucocephala* mean leaf mass per hectare in high density stands was 1.589 t, significantly more than the 1.260 t in medium density plots which, in turn, was statistically different from that of low density plots of 0.862 t ha^{-1}. These results indicate that the number of trees per hectare contributed to significant variations in quantities of leaf fodder per hectare. However, for both species after a year of very low rainfall, i.e. at the age of 4.5 years, the leaf yield per hectare was poor and similar in the different stand densities compared in this study.

Maghembe *et al.* (1986) recorded significant contrasts in leaf yields per hectare in four year old stands of *L. leucocephala* planted at 3 x 3, 4 x 4 and 5 x 5 m in Morogoro, Tanzania, with annual rainfall ranging between 500 and 1200 mm. Their study indicated that the greater number of trees in the high density plots contributed to significantly higher leaf yields per hectare. The corresponding results of this study show that higher density planting will greatly increase the availability of leaf fodder for livestock. The general aridity and variability of Botswana's rainfall favour wider spacing to promote plant survival, ease of management and a reduction of opportunities for pests that will thrive in closely spaced trees where competition for soil moisture and nutrients is severe. As the higher yields in the wettest year (age 6.5 years) were only marginal ($p = 0.0980$), it would seem to be beneficial to employ wider (possibly 6.3 x 5 or 8.3 x

5 m) rather than the maximum of 5 x 5 m used in the study of Maghembe *et al*. (1986), where the mean annual rainfall is higher than in eastern Botswana. In view of the frequency of drought years in Botswana which impose severe water stress on trees, it seems clear that plant mortality can be reduced by adopting a relatively wide spacing. Species x spacing interaction was not significant.

5.2.8.2 Pod Mass per Hectare

L. leucocephala produced significantly greater pod mass per hectare than *L. diversifolia* at all three harvests. The mean yields per hectare were 1.431, 0.406 and 1.535 t for *L. leucocephala* compared to 0.996, 0.184 and 0.561 t for *L. diversifolia* at 2.5, 4.5 and 6.5 years respectively. These results show that even in the driest year *L. leucocephala* was more productive in pod yield than *L. diversifolia* which may contribute to its weediness.

As with leaf mass, pod mass per hectare was significantly greater in high density stands ($p = 0.0001$) at the harvest of trees aged 2.5 years. This trend was followed in the harvest of trees aged 6.5 years but the yields were not significantly different among stands. This would appear to indicate that if trees are allowed to grow over 2.5 years, significant differences will be observed; under a shorter rotation the advantage of high density is not exhibited. As with leaves, it could be suggested that a wider spacing than 5 x 5 m may be preferred as it will reduce competition among plants, reduce diseases and limit the incidence of pests.

Species x spacing interaction was not significant at any of the harvests, even though the p-value was low ($p = 0.0641$) at the harvest of trees aged 4.5 years. This harvest was preceded by a very dry period with seasonal rainfall of only 372 mm. *L. diversifolia* trees appear to have been particularly affected, with those at low density, where there was less competition, yielding 0.301 t ha^{-1} compared to high density trees where the mean yield was only 0.081 t ha^{-1}. On the other hand, the *L. leucocephala* yields among planting densities were similar and did not appear to have been affected by competition for moisture in the high density plots. This appears to indicate that both under drought conditions and in years of high rainfall, plot density does not affect pod mass per hectare.

5.2.8.3 Wood Mass per Hectare

Both species yielded more than two tonnes of woody biomass per hectare, over each two year cycle and thus have great potential to alleviate shortages of fuelwood. *L. leucocephala* produced significantly more wood at the age of 2.5 years than *L. diversifolia*, a mean mass of 3.203 t ha^{-1} compared to 2.516 t ha^{-1}. This trend was repeated at the final harvest of trees aged 6.5 years, at which *L. leucocephala* yielded 3.127 t ha^{-1}in contrast to *L. diversifolia* with a mean mass of 2.207 t ha^{-1}. Significantly greater yields per hectare were obtained for both species from high density plots compared to low density stands at the harvest of trees aged 2.5 years. At 4.5 and 6.5 years statistical significance was not exhibited, suggesting that wide spacing may be preferred.

5.2.8.4 Total Biomass per Hectare

There were significant differences between the biomass yields of the two species at the harvest of 2.5 years ($p = 0.0028$). *L. leucocephala* yielded significantly greater biomass with a mean of 5.87 t ha^{-1} compared to 4.16 t ha^{-1} for *L. diversifolia*. This trend was also apparent at the harvest of trees aged 6.5 years, with a mean yield of 17.86 t ha^{-1} compared to 11.87 t ha^{-1} for *L. diversifolia*. The better yield of *L. leucocephala* could be due to its higher number of stems per tree, especially in the harvest of trees aged 6.5 years when the number of coppice shoots was significantly greater for *L. leucocephala* than for *L. diversifolia* (Fig. 4.22). The results indicate that with high rainfall *L. leucocephala* was more productive than *L. diversifolia*, but that under drought conditions the species were comparable in total biomass.

Except at the age of 2.5 years, when the mean biomass yield of high density trees was significantly greater than that of trees at low density ($p<0.0001$) the yields of different stands were very similar. This lack of difference among stands is important because it is characteristic of both the harvest at the age of 4.5 years which followed a drought year and that at 6.5 years which was preceded by very high rainfall. It provides a very good indication that equally good yields could be achieved at low density and suggests that low density spacing would best suit the

practices in eastern Botswana as it will limit competition among trees and reduce loss of trees compared to closer spacing. Similarly, low density planting will reduce the cost of tree management and, where equipment is available, allow mechanised weeding. Additionally wide spacing will benefit understorey crops, such as *Lablab purpureus* and millet fodder, which exploit nutrients and water at a different soil level to the trees.

Species x spacing interaction was not significant throughout the study. This suggests that, although *Leucaena diversifolia* produced higher yields per hectare at low density, than at high density, while for *L. leucocephala* the highest value was in high density plots, statistically this contrast was not significant (Appendix 5, Table 14).

What is noteworthy between the species was the contribution of the various agroforestry components to total biomass. In 1996, for *L. diversifolia* the contribution of leaf, pod and wood was 15.6, 23.9 and 60.5% respectively, while for *L. leucocephala* the corresponding values were 21.0, 24.2 and 54.8%. In 1998, the leaf, pod and wood contribution for *L. diversifolia* was 5.1, 6.9 and 88.0%, while for *L. leucocephala* the values were 5.3, 13.3 and 81.4% respectively. Following the wetter season prior to the 6.5 years harvest in 2000 the values were 22.1, 15.80 and 62.1%, while for *L. leucocephala* the values were 16.6, 26.6 and 56.8% for leaves, pods and wood respectively. What should be noted is the high contribution of pods to the total biomass of *L. leucocephala*. At all harvests the pod mass of *L. leucocephala* exceeded its leaf mass; this was especially so in the drought conditions preceding the 1998 harvest when the value was double that of *L. diversifolia* and double the leaf mass of the species. This characteristic favours the selection of *L. diversifolia* for planting rather than *L. leucocephala*. However, although *L. leucocephala* is more productive, it is an invasive species. To prevent this species from invading natural vegetation, frequent harvesting of pods will be essential and thus increase labour requirements.

5.2.9 Relationships between Fodder Products

The correlation of parameters of exotic species is presented in Appendix 5, Table 15. The correlation coefficients of agroforestry production are presented in Table 4.4.

For both species Table 4.4 shows that leaf and pod masses were positively correlated at all three years of harvest with similarly high values in the harvests of 1996 and 2000, but a low value in the drought year of 1998. The high correlation of leaf and pod can be expected in years of good rainfall such as at 2.5 (1996) and 6.5 years (2000) since pod formation depends photosynthates produced in the leaves. The r-values at 4.5 years were however low, i.e. 0.2964 and 0.1915 for *L. diversifolia* and *L. leucocephala* respectively. Due to the preceding drought shedding of leaves commenced before harvesting. However the pods, although fewer in number compared to other harvest, were retained much longer and their mean mass was thus disproportionately high compared to that of the leaves. Under drought conditions the relationship between leaves and pods appears difficult to predict.

Leaf and wood mass were highly correlated at all harvests for both species (Table 4.4). The loss of the leaves due to low moisture availability in a drought year would have led to considerable discrepancy in relating the two parameters for both species and could explain why the r-value for the harvest of 1998 was lower than the two years of good rainfall in 1996 and 2000.

When the harvest was preceded by good rainfall, as in 1996 and 2000, the positive correlation between pods and wood for both species was highly significant, with r-values of 0.9234 and 0.7191 for the harvests of trees aged 2.5 and 6.5 years respectively for *L. diversifolia.* The corresponding values were 0.8916 and 7.018 for *L. leucocephala* (Table 4.4). The 1998 harvest, when trees were aged 4.5 years, was preceded by drought and r-values were low fro both species, r = 0.3595 and 0.3770 for *L. diversifolia* and *L. leucocephala* respectively. These relatively low values may result from the fact that wood had been produced over a period of two years, of which the first year was not very dry, whereas the harvested pods were produced during one year of drought.

5.3 CHEMICAL COMPOSITION OF PLANT MATERIAL

5.3.1 General

The chemical composition of leaves of the four browse species is discussed and comparisons are made with those of other studies. They are compared to the values for *Medicago sativa*, bran and *Lablab purpureus* presented in Section 5.3.2, Table 5.1

Chemical composition of oven-dried leaves of the four species in g/100 g of dry matter is presented in Tables 4.5 and 4.6. *M. sativa* is commonly used as a protein supplement for livestock, especially in the dry season. Sorghum bran is used much more extensively than *M. sativa* during the dry season, since it is widely available at milling companies in Botswana. *L. purpureus* is not as commonly used as *M. sativa* or bran, because it is not commercially sold nor is its seed readily available for planting. It was promoted in dry land farming by the Department of Agricultural Research from the late 1980s to the early 1990s (Walker, 1992).

In Botswana *M. sativa* is currently grown under irrigation, using either sewage water or fresh water and is the major fodder imported from South Africa as a supplementary feed for livestock, especially in the dry season.

Table 5.1 Chemical composition of commonly used supplements (g/100 g of dry matter)

Parameter	*M. sativa*	Bran	*L. purpureus*
ADF	28.0-33.64	13.74	29.4-38.6
ADL	5.6-7.16	3.10	6.42-7.1
Ash	5.7-8.99	3.15	15.9[+]
CP	17.42 –19.8	11.60	16.2-17.0
IVDMD	59.2-66.00	48.50	62.1-75.8
NDF	46.57	28.89	43-47
OM	94	97	84.1[+]
Ca	0.88	0.25	2.08[+]
Mg	0.33	0.28	
K	0.24	0.12	
P	0.20	0.62	0.11[+]
Na	0.04	0.06	
Tannin		0.00	1.69[+]

ADF = acid detergent fibre, ADL= acid detergent lignin, CP = crude protein, IVDMD = in vitro dry matter digestibility, NDF= neutral detergent fibre, OM organic matter content. [+]Mupangwa *et al.*, 2000.

5.3.2 Nutritional Composition of Leaves of the Four Species

5.3.2.1 Acid Detergent Fibre (ADF)

ADF varied significantly among leaves of the four species ($p<0.0001$) (Appendix 6, Table 1). The *A. galpinii* value of 37.79 g/100 g of dry matter was significantly greater than those of all other species. The *Leucaena leucocephala* content of 29.85 g/100 g of dry matter was similar to the value of 29.88 g/100 g of dry matter for *F. albida*, both which were significantly lower than that of *L. diversifolia* at 31.88 g/100 g of dry matter (Table 4.5). The ADF value for *A. galpinii* is considerably higher than the figure of 19.87 g/100 g of dry matter reported by Aganga and Nsinamwa (1997). The ADF value of *F. albida* was also high in comparison to the results of other studies *(*Aganga *et al*., 1999; Cisse and Kone, 1992) which reported ADF values of between 19.39 and 22.9 g/100 g of dry matter. For *L. diversifolia* and *L. leucocephala* ADF values of 31.88 and 29.84 g/100 g of dry matter are within the range of the findings of other studies (Felker *et al*., 1999; Khamseekhiew *et al*., 2003; Roothaert and Paterson, 1997; Stewart and Dunsdon, 1998; Wheeler *et al*., 1994).

The ADF content of the leaves of the four species compares well with common sources of protein, such as *M. sativa* and *Lablab purpureus*, which are reported to range from 28.5 to as high as 35 g/100 g of dry matter (Mupangwa *et al*., 2000; Murphy and Colucci, 1999; Wheeler *et al*., 1994).

5.3.2.2 Acid Detergent Lignin (ADL)

A. galpinii had significantly the highest ADL content at 17.54 g/100 g of dry matter, followed by *Leucaena diversifolia* with a value of 12.72 g/100 g of dry matter, which differed little from *F. albida* and *L. leucocephala* with values of 11.89 and 11.03 g/100 g of dry matter respectively (Table 4.5). The low ADL of *L. leucocephala* is indicative of its high palatability and therefore its importance as forage (Shelton and Brewbaker, 1994).

The high value of ADL in *A. galpinii* suggests that it may have low digestibility; it will therefore be necessary to subject it to feeding trials to establish its value as a livestock fodder. Sandoval-Castro *et al*. (2005) found that ADL was negatively correlated to the intake of tree fodder by livestock (r = -0.898). Alternatively the high ADL content of *A. galpinii* may require further processing of fodder in order to improve the utilisation, since this study indicated that this species has great potential as a planted tree in eastern Botswana. The values for *F. albida*, *L. leucocephala* and *L. diversifolia* are comparable with those reported by other researchers (Reed *et al*., 1992; Tolera *et al*., 1998; Wiegand *et al*., 1996). Even for *L. leucocephala,* which had the lowest value of all four species, the ADL content is 5 g/100 g of dry matter higher than those of both *M. sativa* and *Lalab purpureus* listed in Table 5.1. However, valid comparisons can only be made through feeding trials.

5.3.2.3 Ash Content

The ash content varied significantly among the leaves of the browse species ($p<0.0001$) (Appendix 6, Table 1). At 7.36 g/100 g of dry matter *Leucaena leucocephala* had a significantly greater ash content than all the other species. It was followed by *A. galpinii* with a value of 6.47 g/100 g of dry matter which, in turn, had a significantly higher ash content than *L. diversifolia*'s 5.81 g/100 g of dry matter. *F. albida* had a significantly lower value, at 4.58 g/100 g of dry matter, than *L. diversifolia* (Table 4.5). .The values reported for the *Leucaena* species are in line with the results of other studies (Limcangco-Lopez, 1989; Rangkuti *et al*., 1989). While the values of all tree species in this study compare well with that of *M. sativa*, they are lower than that of *Lablab purpureus* which has an ash content of 15.9 g/100 g of dry matter (Table 5.1). All four tree species, even *F. albida* with 4.58 g/100 g of dry matter, had higher values than sorghum bran which has an ash content of 3.15 g/100 g of dry matter (Aganga and Tshwenyane, 2003). Ash content is an indicator of mineral concentration and, as shown later in this study, the mineral content of the tree leaves is comparable to that of *M. sativa* (Table 4.6). Ash content was not significantly influenced by spacing (Appendix 6, Table 1). Species x spacing interaction was highly significant. This indicates that ash content was influenced differently by spacing depending on species, suggesting that mineral uptake will be influenced by spacing differently depending on the species. It follows that since ash content is a measure of mineral concentration

(Stewart and Dunsdon, 1998), mineral uptake is also influenced differently by spacing depending on the species. As shown in section 5.3.3.1, calcium concentration species x spacing interaction was also significant. For example, although the relationship is not straightforward, *Leucaena leucocephala* had a high ash content and a similarly high Ca concentration at low density where the species would have had an increased capacity to extract minerals compared to trees at high or medium density. On the other hand, the *F. albida* ash content did not differ much among spacing and neither did its phosphorus content.

5.3.2.4 Crude Protein (CP)

The results show that the difference in the crude protein content of leaves of the four species was highly significant ($p<0.0001$) (Appendix 6, Table 1). As shown in Table 4.9, *F. albida,* at 25.25 g/100 g of dry matter, had significantly the highest CP of the four species, followed by *A. galpinii* with 18.72 g/100 g of dry matter. *L. leucocephala* had a significantly higher CP content than *L. diversifolia,* with values of 17.11 and 16.26 g/100 g of dry matter respectively.

Variations in the nutritional value of browse among species can be expected. Stewart and Dunsdon (1998) reported variations in nutrition among several *Leucaena* species including *L. leucocephala* and *.L. diversifolia* harvested from the same site in Honduras. The crude protein content of *A. galpinii* leaves in this study was greater than that of browse forage analysis of the species collected in the Central District of Botswana by Aganga and Nsinamwa (1997) who recorded a value of 15.62 g/100 g of dry matter. Mokoboki *et al.* (2005) collected leaves from *A. galpinii* trees along the Limpopo River in South Africa and reported a value of 14.96 g/100 g of dry matter. Although there has been little research on the species, the difference of a little over 3 g/100 g of dry matter between their results and those of this study could be expected, as variations in plant nutrition may be influenced by soil fertility as well as by the maturity of plants (Larbi *et al*., 2005; Stewart and Dunsdon, 1998).

The results obtained for *F. albida* fall within the range of between 20.1 g/100 g of dry matter reported by Reed *et al.* (1992), based on 7 month old plants collected in Niamey, Niger, and 29 g/100 g of dry matter reported by Aganga *et al*. (1999) from leaves of trees collected from the Tuli block in Botswana. For *L. diversifolia* and *L. leucocephala* the values of 16.25 and 17.11 g/100 g of dry matter obtained in this study fall within the wide range of values reported by other researchers which vary between of 12.8 to 27.5 g/100 g of dry matter for dried leaves of the species (Aregheore, 2002; Felker *et al*., 1999; Karachi, 1998; Mandal, 1997; Nyambati *et al*., 1996; Wheeler *et al*., 1994). Aregheore (2002) in Apia, Samoa, found variation in the CP content of dry, wilted and fresh leaves of *L. leucocephala* from the same batch harvest.

The results show that all four browse species had at least twice as much crude protein as the 8 g/100 g of dry matter required for the maintenance of livestock (Norton, 1994; Rubanza *et al*., 2003) and consequently can be used as supplements. The leaves of the four species compare well with the crude protein content of popular protein supplements such as *M. sativa*, whose reported value is between 17 to 19.8 g/100 g of dry matter and *Lablab purpureus* with values from 10 to 22 g/100 g of dry matter (Murphy and Colucci, 1999; Mupangwa *et al*., 2000; Sekine *et al*., 2003). It is higher than that of sorghum bran which has a typical value of 11.6 g/100 g of dry matter (Aganga *et al*., 1999; Aganga and Tshwenyane, 2003; Mupangwa *et al*., 2000). This indicates that leaves of the four species have the potential to contribute protein, the insufficiency of which is a major limiting factor in the improvement of livestock production in Africa (Devendra, 1990; Rubanza *et al*., 2003).

5.3.2.5 In Vitro Dry Matter Digestibility (IVDMD)

Contrasts in *in vitro* dry matter digestibility were statistically significant ($p<0.0001$) among leaves of the four species (Appendix 6, Table 1). At 82.28 g/100 g of dry matter, *Leucaena leucocephala* had a significantly higher value than all the other species, while *F. albida*, with 79.67 g/100 g of dry matter, had a significantly greater percentage than *L. diversifolia* at 76.28 g/100 g of dry matter. In line with its high ADL, *A. galpinii* recorded a significantly lower IVDMD content, with a value of 74.91 g/100 g of dry matter, than those of the other three species. This is to be expected as the species had high lignin content which reduces the digestibility of fodder. The IVDMD values for *L. leucocephala* and *L. diversifolia* are

comparable to those of other studies (Felker *et al*., 1999; Wheeler *et al*., 1994; Wiegand *et al*., 1996). The *F. albida* value of 79.67 g/100 g of dry matter is greater than the 67.6 g/100 g of dry matter reported by Wiegand *et al.* (1996), but could be influenced by the predominance of small, young leaves in the samples analysed in this study. It was also comparable to those of the commonly used feed supplements, *M. sativa* and *Lablab purpureus*. There were no significant differences in IVDMD concentration at different spacings ($p = 0.0549$). Species x spacing interaction was significant (Appendix 6, Table 1) (Table 4.5). This suggests that the *in vitro* dry matter digestibility of each species was influenced differently by spacing. For example while for *Leucaena diversifolia* and *L. leucocephala* IVDMD value was highest in low density with *A. galpinii* the highest value was in medium density and while *F. albida* lowest value was in medium density.

5.3.2.6 Neutral Detergent Fibre (NDF)

NDF varied significantly among the leaves of the four species ($p<0.0001$) as shown in Appendix 6, Table 1. While *A. galpinii* (33.65 g/100 g of dry matter), *L. diversifolia* (34.36 g/100 g of dry matter) and *L. leucocephala* (34.61 g/100 g of dry matter) did not differ significantly in NDF content, all three had significantly greater values than *F. albida* (Table 4.5). The NDF values of leaves of all species accord with those of other researchers (Aregheore, 2002; Cisse and Kone, 1992; Stewart and Dunsdon, 1998; Wiegand *et al*., 1996), with the exception of *A. galpinii* which is little researched. With an NDF content of 33.65 g/100 g of dry matter, its value was much higher than the 22.62 g/100 g of dry matter given by Aganga and Nsinamwa (1997) from their Botswana national browse analysis data, but the value for this study is lower than the 50.90 g/100 g of dry matter recorded by Mokoboki *et al*. (2005) from their samples of *A. galpinii* leaves collected from along the Limpopo River. Similar variations of NDF have been recorded in other species so that the difference between the results of this study and those of Aganga and Nsinamwa (1997) is not unique to *A. galpinii*. The NDF contents of the leaves of the four species are comparable to that of sorghum bran but lower than those of the nutritious *M. sativa* and *Lablab purpureus* with values of 46.57 and 43-47 g/100 g of dry matter respectively (Table 5.1).

5.3.2.7 Organic Matter (OM)

At 95.43 g/100 g of dry matter *F. albida* had a significantly the higher OM in its leaves than *Leucaena diversifolia*, whose value of 94.17 g/100 g of dry matter was statistically greater than that of *A. galpinii* at 93.53 g/100 g of dry matter. *L. leucocephala* had significantly the lowest value with an OM content of 92.68 g/100 (Table 4.5). The OM was not significantly influenced by spacing, but species x spacing interaction was highly significant ($p<0.0001$), indicating that spacing influenced OM content of each species differently. The values obtained for *L. leucocephala* were in agreement with those of Aregheore (2002) of between 90.50 and 95.0 g/100 g of dry matter, as well those of Khamseekhiew *et al*. (2003) of 96.6 g/100 g of dry matter. The OM content of the leaves of all four species was comparable in value to that of *M. sativa* (Table 5.1). The high OM value is in accordance with a low value for ash content which is an indicator of the mineral content. For example, the leaves which have a higher ash content than pods also have a higher calcium content than the pods.

5.3.2.8 Condensed Tannin (CT)

Condensed tannin content was significantly different ($p<0.0033$) among leaves of the four browse species. *F. albida* had a significantly lower tannin content of 1.89 g/100 g of dry matter than *A. galpinii*, *L. leucocephala* and *L. diversifolia*, whose values were 2.14, 2.12 and 2.04 g/100 g of dry matter. The last three did not differ significantly among themselves (Table 4.5). Spacing did not influence condensed tannin content.

All four browse species were considerably lower than 6 g/100 g of dry matter, a level which inhibits the utilisation of feed (Norton, 1994; Rubanza *et al*., 2003). All four species contained higher concentrations of condensed tannin than the 1.69 g/100 g of dry matter in *Lablab purpureus* reported by Mupangwa *et al*.(2000). The results therefore indicate that from the point of view of CT these species have considerable potential as feed and should be evaluated in feed trials along with commonly used supplements.

5.3.3 Mineral Composition

5.3.3.1 Calcium Content (Ca)

Calcium concentration in leaves varied significantly among the species ($p<0.0001$), as shown in Appendix 6, Table 2. *A. galpinii* had a significantly higher value (1.20 g/100 g of dry matter) than the three other species, while *Leucaena leucocephala* had a higher concentration (1.04 g/100 g of dry matter) than both *L. diversifolia* (0.93 g/100 g of dry matter) and *F. albida* which had the lowest at 0.54 g/100 g of dry matter (Table 4.6). The results may suggest that the better adapted *A. galpinii* was able to extract calcium from the soil more readily than both *F. albida* and the exotic species. In contrast to the nutritional compounds (Appendix 6, Table 1), there were significant differences in the concentration of the mineral calcium in the leaves of plants at different spacings ($p<0.0001$) (Appendix 6, Table 2). Species x spacing interaction was also significant ($p<0.0001$). As shown in Table 4.6, spacing influenced the concentration of calcium differently; in both *A. galpinii* and *L. leucocephala* the calcium concentration was greatest in low density plots and lowest in the high density plantings. This could be explained by the better availability of nutrients in the soil to individual trees at low density stands. *F. albida* had the lowest value in high density plots, with the highest concentration in medium density stands. Values for *L. diversifolia* were marginally highest in high density stands and lowest in medium density plots, but did not vary greatly between stands.

These results are very important as the purchase of dicalcium phosphate is one of the major expenses farmers face in order to reverse the deficiencies in calcium which commonly occur in livestock in Botswana. Use of these browse species could address some of the shortfall. The concentration in *L. leucocephala* accords with that reported by Karachi *et al.* (1997) in Tumbi, Tanzania, where they recorded a value of 1.1 g/100 g of dry matter which compares well with the 1.04 g/100 g of dry matter of this study. All four species have lower calcium concentrations than the content of 2.08 g/100 g of dry matter in *Lablab purpureus* (Mupangwa *et al.*, 2000), suggesting that the integration of these browse species with *L. purpureus* could improve the opportunities for providing calcium through fodder production on-farm. *A. galpinii, Leucaena leucocephala* and *L. diversifolia,* had fairly comparable calcium values (1.20, 1.04 and 0.93

g/100 g of dry matter) to that of *M. sativa* grown in Botswana with a concentration of 0.88 g/100 g of dry matter (Aganga and Tshwenyane, 2003), while *F. albida* had a concentration of only just over half its value (0.54 g/100 g of dry matter).

5.3.3.2 Potassium Content (K)

The results show that there were significant differences in potassium concentration among the species ($p<0.0001$), as shown in Appendix 6, Table 2. *A. galpinii* (0.65 g/100 g of dry matter) had a significantly greater value than *F. albida* (0.58 g/100 g of dry matter) and *L. diversifolia* and had a similar value to *L. leucocephala* (0.61 g/100 g of dry matter). *L. diversifolia* had the lowest value at 0.50 g/100 g of dry matter. These results may reflect the advantage of well-adapted species, such as *A. galpinii*, in being able to extract minerals from nutrient-deficient soils.

The value obtained for *L. leucocephala*, at 0.61 g/100 g of dry matter, was less than half of the 1.27 g/100 g of dry matter recorded by Karachi *et al.* (1997) in trees planted in Tumbi, Tanzania, but higher than the value of 0.0185 g/100 g of dry matter reported by Aregheore (2002) from his study in Apia, Samoa. All four species have higher values than the conventional feeds of *M. sativa* and sorghum bran at 0.24 and 0.12 g/100 g of dry matter respectively (Aganga and Tshwenyane, 2003).

5.3.3.3 Magnesium Content (Mg)

L. leucocephala had by far the highest mean value of magnesium in its leaves, with the lowest concentration being found in *F. albida* (Table 4.6). The contents of the leaves were 0.64, 0.53, 0.37 and 0.27 g/100 g of dry matter for *L. leucocephala, A. galpinii, L. diversifolia* and *F. albida* respectively. The relatively high magnesium content of *A. galpinii* emphasises the potential of this little-known species. This is especially so in view of the much lower concentration in the more researched *F. albida*, which does not do well under semi-arid conditions and had the lowest value.

L. leucocephala and *A. galpinii* had higher values than the commonly used supplements, *M. sativa* and sorghum bran ,which have concentration of magnesium of 0.33 and 0.28 g/100 g of dry matter respectively (Aganga and Tshwenyane, 2003, 1997; Mupangwa *et al*., 2000), while *L. diversifolia* and *F. albida* had comparable values. Spacing did not affect the concentration of magnesium. However, species x spacing interaction was significant (Appendix 6, Table 2). As shown in Table 4.6, the highest value for *L. leucocephala* was in low density plots where trees would have had greater opportunity to extract minerals, while for *A. galpinii* and *F. albida* the highest value was at medium density. Both the indigenous trees had the lowest values in high density plantings where there was greater competition for mineral uptake by individual plants.

5.3.3.4 Sodium Content (Na)

As shown in Appendix 6, Table 2, there were significant contrasts in the sodium content of the leaves of the different species ($p<0.0001$), with a comparatively high value of 0.0030 g/100 g of dry matter in *F. albida*. This was significantly higher than the concentrations in *A. galpinii and L. leucocephala*, both of which had a value of 0.0027 g/100 g of dry matter. *L. diversifolia* had the lowest value at 0.0025 g/100 g of dry matter (Table 4.6). However, emphasising such contrasts when the means are so low is of little consequence.

The concentrations of sodium in all four browse species are much lower than those given for *M. sativa* and sorghum bran at 0.33 and 0.28 g/100 g of dry matter respectively (Aganga and Tshwenyane, 2003). This suggests that potential benefits may follow from combining plantings of browse species with other supplementary feeds for livestock.

5.3.3.5 Phosphorus Content (P)

Phosphorus concentration was significantly different among the leaves of the four species ($p<0.0001$) (Appendix 6, Table 2). The value for *F. albida*, at 0.24 g/100 g of dry matter, was significantly higher than the 0.19 g/100 g of dry matter phosphorus content for both *A. galpinii* and *L. leucocephala*, which was considerably greater than that of *L. diversifolia* (0.17 g/100 g of dry matter). Only *F. albida* had the 0.24 g/100 g of dry matter minimum requirement for livestock maintenance suggested by Norton (1994). This suggests that the use of browse may not fully address phosphorus deficiencies in livestock in Botswana which will need to be remedied by the utilisation of additional feeds. Most farmers have access to sorghum bran, either from their own crop or through commercial sources which are widely available commercial sources. Sorghum bran contains 0.62 g/100 g of dry matter phosphorus (Aganga and Tshwenyane, 2003), a much higher concentration than in the four species analysed in this study. However, the commonly used supplements have magnesium contents which are comparable to the low values found in this study with concentrations of only 0.11 g/100 g of dry matter in *Lablab purpureus* (Mupangwa *et al*., 2000) and 0.20 g/100 g of dry matter in *M. sativa* (Aganga and Tshwenyane, 2003)

5.3.4 Comparison of Nutritional Composition of Leaves and Pods of Exotic Trees

5.3.4.1 General

The importance of finding a solution to shortages of on-farm feed through utilisation of browse remains a major focus of this study. Literature to compare the importance of browse largely covers tree leaves as a protein source, but pays limited attention to pods. This may be associated with the fact that most research is conducted on-station, as suggested by Franzel and Scherr (2002), or has been conducted in wetter environments where the major emphasis has been on the harvesting of leaves for green manure. It may also be associated with the fact that the early harvesting of trees, before pods mature, reduces potential for self-seeding of *Leucaena leucocephala* which leads to weediness on-farm. The other possibility might be that pods have higher tannin concentration than the leaves, as shown by the results of this study, which is

commonly regarded as imposing a threat to the health of livestock. Comparisons of the nutritive value of leaves and pods of *L. diversifolia* and *L. leucocephala* are presented in Section 4.3.3.

5.3.4.2 Acid Detergent Fibre (ADF)

In both species pods had significantly higher values for ADF than the leaves. *L. diversifolia* pods had a value of 36.60 g/100 g of dry matter, which was considerably higher than the leaves, with a content of 31.88 g/100 g of dry matter (Table 4.7). With *L. leucocephala* the values were 34.40 and 29.84 g/100 g of dry matter for pods and leaves respectively (Table 4.8). These values accord with those of seed pods in the study of Nyambati *et al*. (1996) which range from 20 g/100 g of dry matter in immature pods to 42 g/100 g of dry matter in mature, dry pods. Although in both species the value was significantly higher in pods, the ADF recorded for pods in this study compares well with those of the leaves of *Leucaena* species in other studies which range from 25 to 49 g/100 g of dry matter (Aregheore, 2003; Wheeler *et al*., 1994). The NDF value for pods also compares favourably with those of reputable feeds such as *M. sativa*, sorghum bran and *Lablab purpureus,* which range from 28 to 47 g/100 g of dry matter (Aganga and Tshwenyane, 2003; Sekine *et al*., 2003; Wiegand *et al*., 1996). These results indicate that pods could play an important role in feeding livestock.

5.3.4.3 Acid Detergent Lignin (ADL)

For both *Leucaena diversifolia* and *L. leucocephala* the leaves and pods did not vary significantly in lignin content (Appendix 6, Tables 3 and 4). The values for pods were 12.92 and 11.74 g/100 g of dry matter for *L. diversifolia* and *L. leucocephala* whereas their leaves had 12.72 and 11.03 g/100 g of dry matter respectively. These are very promising results, as lignin has been found to be negatively correlated to the acceptance of feed (Sandoval-Castro *et al*., 2005). The results therefore give a good indication of the potential acceptability of pods in supplementary feed.

5.3.4.4 Ash Content

The ash content of leaves was considerably greater than that of pods, suggesting that pods should have lower mineral content (Tables 4.7 and 4.8). As shown in this section (5.3.3.10), the calcium concentration was indeed lower in pods than in leaves. Despite the low values, 5.1 g/100 g of dry matter compared to 5.81 g/100 g of dry matter for leaves of *L. diversifolia* and 5.92 g/100 g of dry matter in contrast to 7.36 g/100 g of dry matter for *L. leucocephala,* the ash content was similar to the value obtained by Aganga and Tshwenyane (2003) for *M. sativa* grown in Botswana and that given by Han *et al.* (2000) of 5.73 g/10g of dry matter.

5.3.4.5 Crude Protein (CP)

CP, which is not readily available from forage for livestock production in arid zones (Rubanza *et al*., 2003), was significantly greater in the pods of both species than in their leaves ($p<0.0001$) (Appendix 6, Tables 3 and 4). For *L. diversifolia* the crude protein contents were 17.51 g/100 g of dry matter for pods and 16.26 g/100 g of dry matter for leaves, while for *L. leucocephala* the equivalent values were 19.72 and 17.11 g/100 g of dry matter (Tables 4.7 and 4.8). The contrast is associated with the high protein content of the seeds contained in pods. In emphasising the importance of pods, it is worth noting that much of the crude protein will be concentrated in the seeds (Nyambati *et al.*, 1996). Consequently, the management of trees that produce edible fodder will require early harvesting of pods so that they retain the maximum number of seeds, both during the harvest and throughout the drying process. Similarly pods, which are readily accepted by animals unprocessed, will have to be harvested while immature so that the kraal manure which is used on the farm does not become a source of mature viable seed that will germinate and lead to species invasion on farm land or the range.

From the results of yield per tree and the crude protein at different spacings for both leaves and pods the crude protein yield per hectare are presented in Table 5.2.

Table 5.2 Crude protein of L. diversifolia *and* L. leucocephala *biomass on a dry matter basis (kg ha^{-1})*

Year (Age yrs)	Species	Spacing (m)	Leaf	Pods
1996 (2.5)	*L diversifolia*	5	145.85 ± 3.22a	241.56 ± 4.01b
		6.3	93.19 ± 5.20b	162.50 ± 4.60b
		8.3	75.00 ± 5.70c	122.47 ± 4.07c
	Mean		**105.20b**	**174.40a**
	L leucocephala	5	272.99 ± 5.89	336.32 ± 5.34
		6.3	224.66 ± 6.38	319.56 ± 4.83
		8.3	140.51 ± 4.06	188.75 ± 5.51
	Mean		**211.65b**	**282.19a**
1998 (4.5)	*L. diversifolia*	5	31.85 ± 0.86	14.58 ± 1.97c
		6.3	16.56 ± 1.38	29.45 ± 2.26b
		8.3	19.35 ± 1.53	51.20 ± 2.00a
	Mean		**22.60**	**32.22**
	L. leucocephala	5	29.89 ± 1.58a	80.81 ± 2.62a
		6.3	29.06 ± 1.71a	97.85 ± 2.37a
		8.3	24.94 ± 1.09a	61.52 ± 2.70b
	Mean		**27.89**	**80.06**
200 0(6.5)	*L. diversifolia*	5	146.18 ± 3.04	87.66 ± 4.38
		6.3	109.91 ± 4.86	57.85 ± 5.03
		8.3	126.86 ± 5.39	147.14 ± 4.45
	Mean		**127.64**	**98.23**
	L. leucocephala	5	190.70 ± 5.56a	322.27 ± 5.84a
		6.3	173.49 ± 6.02b	270.53 ± 5.28b
		8.3	112.47 ± 3.83c	313.98 ± 6.02a
	Mean		**161.79**	**302.70**

Means in a column followed by different letters abc are significantly different among spacings within species within year of assessment $p \leq 0.05$

The crude protein yield of pods was significantly greater than that obtained from leaves except for *L. diversifolia* in the year of high rainfall in 2000 when the leaf crude protein obtained was greater. This is associated with the higher leaf mass yield as the species sets pods much later than *L. leucocephala* which pods much more readily. In all years *L. leucocephala* yielded more biomass in pods than in leaves. This, coupled with the higher crude protein in pods, on a dry

matter basis, means that *L. leucocephala* pods will make a greater contribution to farm crude protein than leaves. The constraints in Botswana are those of poor soils and low rainfall which limit the use of high density planting. The poor soils also mean that the crude protein content in both leaves and pods of planted *L. leucocephala* will be low. In high potential areas of Kenya and Tanzania, for example, crude protein contents of 26 g/100 g of dry matter and 23.3 g/100 g of dry matter were obtained (Abate *et al*., 1985; Kavana *et al*., 2005) for *L. leucocephala* compared to an average of 17.11 g/100 g of dry matter in this study. Coupled with the potential to grow trees at much closer spacing than in this study the species can contribute better yields of crude protein under such conditions. However, in Botswana higher density spacing under erratic rainfall could compromise yields and the quatity of crude protein that can be realised. In Malawi, at both Bunda College of Agriculture and Bvumbwe Agricultural Research Station, the crude protein obtained for *L. diversifolia* was also considerably higher than in this study, with a mean value of 21.3 g/100 g of dry matter compared to 16.26 g/100 g of dry matter at Malotwana. The fodder yields ranged from 1011 to 1540 kg/ha^{-1} (Phiri *et al*., 2000). This will lead to a much higher crude protein yield per hectare. As with *L. leucocephala,* much closer spacing, facilitated by better soils and a higher mean annual rainfall of 1 100 mm, provides for much better yields than can be achieved in Botswana where the trial site had annual rainfall totals ranging between 372.4 mm and 728.1 mm during this study.

5.3.4.6 In Vitro Dry Matter Digestibility (IVDMD)

For both species IVDMD was significantly greater in leaves than in pods (Tables 4.7 and 4.8) (Appendix 6, Tables 3 and 4). Thus, despite the potential role of the pods in nutrition, leaves should remain by far the preferred product because of their high digestibility. The IVDMD of pods, with values 69.34 and 73.39 g/100 g of dry matter for *Leucaena diversifolia* and *L. leucocephala* respectively compared to the corresponding values 76.28 and 82.28 g/100 g of dry matter for leaves, falls within the range contained in the leaves of *Leucaena* in other studies of 70.3 and 75.7 g/100 g of dry matter (Shenkoru and Mekonnen, 1994; Wiegand *et al*., 1996). They compare well with those of *M. sativa* (59 to 66 g/100 g dry matter) and *Lablab purpureus (*62-75.8 g/100 g of dry matter), as shown in Table 5.1, which is an indication of the potential role the pods could play as a feed supplement. In comparing leaves and pods it must be noted

that unless leaves are dried in very small quantities, they are highly susceptible to mould. This is in contrast to pods which proved easy to dry and maintain their quality over relatively long periods of storage (three months storage so far without deteriorating). This indicates that despite their lower IVDMD, pods have an added advantage as dry season fodder when crude protein is particularly difficult to supply from forage and comes at a high price from vendors.

5.3.4.7 Neutral Detergent Fibre (NDF)

The NDF values were significantly greater in pods than in leaves ($p<0.0001$), as shown in Appendix 6, Tables 3 and 4. The values were 37.97 g/100 g of dry matter for *Leucaena diversifolia* and 38.64 g/100 g of dry matter for *L. leucocephala,* while leaves contained 34.61 and 34.36 g/100 g dry matter respectively. These values are comparable with those of the leaves of *L. leucocephala* K8 and K636 with NDF contents of 35.5 and 39.0 g/100 g of dry matter (Stewart and Dunsdon, 1998). The values in this study are lower than those of 46.57 g/100 g of dry matter for *M. sativa* and 43-47 g/100 g of dry matter for *Lablab purpureus* in the feeds presented in Table 5.1. This suggests that pods should be recommended for fodder, given their higher crude protein content, and the fact that they are also much easier to dry, as was observed in this study.

5.3.4.8 Organic Matter (OM)

The OM content was significantly higher in pods than in leaves for both species ($p<0.0001$), as shown in Appendix 6, Tables 3 and 4. The values were 94.17 g/100 g of dry matter for leaves of *Leucaena diversifolia* compared to 94.83 g/100 g of dry matter in pods, while for *L. leucocephala* the values were 92.68 and 94.11 g/100 g of dry matter respectively. OM content of 88 to 94 g/100 g of dry matter have been reported for the leaves of *Leucaena* by Stewart and Dunsdon (1998). Such values are comparable with those of leaves and pods in this study (Tables 4.7 and 4.8). The OM contents of both pods and leaves are comparable to that of *M. sativa* with a value of 94 g/100 g of dry matter as reported by Aganga and Tshwenyane (2003).

5.3.4.9 Condensed Tannin (CT)

The concentration of tannin was significantly higher in the pods than in the leaves of both *L. diversifolia* and *L. leucocephala* (Appendix 6, Tables 3 and 4) (Tables 4.7 and 4.8). However, the contents in the pods were only 2.38 and 2.25 g/100 g of dry matter respectively, compared to 2.04 and 2.12 g/100 g of dry matter in leaves. The tannin contents of both leaves and pods were higher than the 1.69 g/100 g of dry matter reported for *Lablab purpureus* (Table 5.1). Since both leaves and pods of the two species are more tanniferous than *L. purpureus* and *M. sativa*, their possible deleterious effects when fed to livestock need to be monitored. What is also of importance, is that the tannin content of both leaves and pods was lowest from trees in low density plots. This suggests that where there is less competition for nutrients tannins may be lower in edible fodder and therefore the use of low density planting can be recommended.

5.3.5 Mineral Composition of Leaves and Pods of Exotic Trees

5.3.5.1 Calcium Content (Ca)

The calcium concentration was significantly greater in the leaves of both species than in their pods. As shown in Table 4.9, *Leucaena diversifolia* leaves had a calcium content of 0.93 g/100 g of dry matter compared to only 0.36 g/100 g of dry matter in its pods, while Table 4.10 shows corresponding values for *L. leucocephala* of 1.04 and 0.52 g/100 g of dry matter. Spacing did not influence the calcium content of *L. diversifolia*, but both spacing and part x spacing interaction were significant for *L. leucocephala* (Appendix 6, Tables 5 and 6). Both pods and leaves had more than the minimum 0.24 g/100 g of dry matter calcium content required for livestock maintenance (Norton, 1994). The values for calcium in the leaves of both species are comparable to that found in *M. sativa* of 0.88 g/100 g of dry matter. However, the calcium content exceeds that of the sorghum bran which is commonly used as feed in Botswana, which at 0.25 g/100 g of dry matter barely meets the minimum livestock requirement. This underlines the considerable potential of leaves and pods to contribute to supplementary feed on-farm, either on their own or in combination with bran which is high in phosphorus. The high calcium content of both leaves and pods of these species is particularly important in the light of the high cost

(P188.00 for 50kg bag at current prices US$32.15) of the supplement of this mineral which is important in bone development of young lambs and in lactating ewes. It also improves the appetite of animals, leading to a higher mass gain than when deficiencies in calcium are present (Underwood and Suttle, 2001).

5.3.5.2 Potassium Content (K)

Pods of *L. diversifolia* contained significantly higher quantities of potassium than the leaves ($p<0.0001$). As shown in Table 4.9, values were 0.69 and 0.50 g/100 g of dry matter respectively. In contrast, for *L. leucocephala* the difference between pods and leaves was not significant ($p = 0.1697$) (Table 4.10), with values of 0.61 and 0.58 g/100 g of dry matter for leaves and pods respectively. This can be explained by the fact that immature *L. diversifolia* pods have a high concentration of potassium which is being translocated from the leaves to the young pods. Since *L. leucocephala* produces pods earlier in the season than *L. diversifolia*, the potassium content of pods and leaves were at an equilibrium in equally mature parts. Consequently pods and leaves had similar potassium content values. The mean potassium concentrations for both leaves and pods were considerably greater than those of *M. sativa* and bran with values of 0.24 and 0.12 g/100 g of dry matter respectively. Of importance is that both the leaves and pods of the two species had potassium values above the minimum requirement of 0.5 g/100 g of dry matter (Aganga and Nsinamwa, 1997). Potassium is important as cellular constituent in relation to sodium movement and to the uptake of amino acids. It also facilitates the absorption of magnesium which is vital to many body functions of the animal (Underwood and Suttle, 2001).

5.3.5.3 Magnesium Content (Mg)

The magnesium content was significantly higher in the leaves of both species than in their pods, as shown in Tables 4.9 and 4.10. The values for *L. diversifolia* were 0.37 and 0.27 g/100 g of dry matter respectively, while for *L. leucocephala* corresponding values were 64 and 0.36 g/100 g of dry matter. While *L. diversifolia* had a relatively low value, the *L. leucocephala* magnesium content compares well with that of *M. sativa* at 0.33 g/100 g of dry matter. The magnesium

content in these browses will improve bone deposition in lambs and also facilitate their metabolism of carbohydrates. Therefore the benefits to be derived from pursuing the integration of browse products with currently-used feeds cannot be over-emphasised.

5.3.5.4 Sodium Content (Na)

In both species the sodium concentration was significantly higher in pods than in leaves. The differences were statistically significant ($p<0.0001$) (Tables 4.9 and 4.10). The sodium contents for *L. diversifolia* leaves and pods were 0.0040 and 0.0025 g/100 g of dry mater respectively, while for *L. leucocephala* the corresponding values were 0.0034 and 0.0027 g/100 g of dry matter. These means were considerably lower than those of both *M. sativa* and sorghum bran at 0.04 and 0.06 g/100 g of dry matter. However, these low values are consistent with the generally low sodium content of most plant tissues other than that of halophytes such as *Atriplex numularia* (Aganga and Nsinamwa, 1997). Sodium is very important mineral in the biochemical functions of the animal; it should always be in balance with potassium as it is important in maintaining osmotic pressure in the body. Fortunately it is readily available in Botswana as it is an essential feed supplement in the successful rearing of livestock in the country.

5.3.5.5 Phosphorus Content (P)

The phosphorus contents in the pods of *L. diversifolia* and *L. leucocephala* were significantly higher than in the leaves (Appendix 6, Tables 5 and 6 and Tables 4.9 and 4.10). The values were 0.23 g/100 g of dry matter in pods of *L. divesifolia* compared to 0.17 g/100 g of dry matter in the leaves. For *L. leucocephala* the phosphorus content of 0.25 g/100 g of dry matter for pods was significantly greater than the value for leaves of 0.19 g/100 g of dry matter. As indicated in the earlier observations about minerals, these results are also influenced by the fact that the relationship between leaves and pods is that of source and sink; consequently higher values can be expected for the pods which are relatively immature compared to the leaves from which minerals are mobilised during the formation and development of pods. As with calcium, phosphorus is a major constituent in bones and teeth and is important in the total metabolism of the animal Deficiencies in the mineral can also limit protein synthesis. It is major cost and a

supplement currently met through purchase of dicalcium phosphate. By using both pods and leaves farmers can enhance the availability of the two minerals in the diet of animals

5.4 GROWTH OF BROWSE-FED LAMBS COMPARED TO THE CONTROL GROUP

5.4.1 General

Although there is substantial interest in browse feeding among many disciplines, e.g. animal health, animal production and agroforestry, the literature on feeding is very scanty, especially for sheep. The considerable amount of information reviewed was largely on feeding trials for beef cattle, pigs and poultry (Larsen *et al*., 1998; Nyambati *et al*., 1998). Therefore literature on goats (Aganga *et al*., 1999; Karachi and Zengo, 1998) has been used in this study as the species are related, even though goats are much hardier than sheep. The nutritional composition of feed given to lambs is presented in Table 4.11. As indicated, the control group was supplemented with bran to avoid animal mortality.

5.4.2 Contribution of Browse to Growth of Lambs

There were significant differences in mass gain of the two groups at various stages of the comparative study of the control and the browse-fed groups of lambs. However, at the final release to the farm the difference between the mean masses was not significant (Table 4.12). During the first four weeks the mass gain was similar between the browse-fed group and the control group (Fig. 28). This similar response of the two groups in the first weeks may have been influenced by the fact that previously all the lambs had experienced a very low feed supply from the veldt. Also important is the fact that measurements taken on day 21 indicated a higher mean mass value for the bran group, as shown in Figure 4.28. This superior performance of the control group might be explained by their more rapid adjustment to bran, which they are accustomed to, because bran is used to supplement the main flock on the farm. Since lambs begin to feed a week after birth they would be familiar with bran, albeit at a lower level. On the other hand, the browse-fed lambs needed time to adjust to an unfamiliar feed with a higher tannin content (0.67 g/100 g of dry matter) (Table 4.11). Consequently the benefit of the higher

nutrition of the browse was not obvious at this early stage, since the lambs required an additional period of adjustment to the feed.

Throughout the feeding trial the browse-fed lambs performed better than the control group, and by the 49th day browse-fed lambs had a significantly higher mean mass than the control group ($p = 0.0245$), as shown in Appendix 7, Table 1. During the unseasonably cold weather of November 2001 (Appendix 1, Table 1), the browse-fed lambs were less affected than the control group (Fig. 4.28). This was observed between days 77 and 112 when the cold conditions caused declines in the mean masses of the two groups. This led to significantly different mean masses, starting at the measurements on day 84 with a low p-value ($p = 0.0645$). The passage of further cold fronts led to an increased difference between the mean masses of the two groups on day 98 ($p = 0.0174$) (Appendix 7, Table 1). Once the temperatures returned to more normal levels the recovery was also at different rates as shown on day 112 when the p-value comparing mean masses was 0.0712. As shown in Table 4.11, the crude protein of the browse-fed group was 11.25 g/100 g of dry matter compared to 7.69 g/100 g of dry matter for the control group. These results appear to demonstrate that the control group had sufficient crude protein for basic maintenance but a somewhat lower value than the 8 g/100 g of dry matter required to sustain growth when part of the energy was needed to maintain body temperature (McDonald *et al*., 1973).

The mean mass gain per animal throughout the trial period was 2.03 kg higher for the browse group than for the control group. Even though this does not constitute a statistically significant contrast in the final mass (Table 4.12), it indicates that browse feed can contribute to livestock rearing and also reduce production costs. The lack of significant difference at final release is probably associated with the fact that the growth of lambs follows a sigmoidal pattern (McDonald *et al.*, 1973). Consequently, with the approach of maturity there would have been a tendency for the mean mass of the control group to catch up with that of the browse-fed lambs.

The contribution of browse as feed in these results compares favourably with the findings of Aganga and Monyatsiwa (1999) whose goat trial was based on the use of *Terminalia sericea, Uclea schimperi* and *Combretum apiculatum,* which demonstrated considerable potential in contributing to livestock mass gain. In their study goats given branches of these species, as supplements gained 64, 67 and 77 g/head/day respectively, compared to the 103g/head/day that was recorded in this study (Table 4.12) when *L. diversifolia* and *L. leucocephala* were used as supplement. These three species, although indigenous to Botswana, are not as easy to cultivate as *L. diversifolia and L. leucocephala.*

In Tanzania, Karachi and Zengo (1998) studied the growth of goats fed browse of *L. leucocephala, Sesbania sesban* and *Cajanus cajan* as supplements. In their study the groups fed *L. leucocephala* and *C. cajan* showed a significantly ($p<0.05$) greater mass gain than the control group. Further, they showed that goats fed *L. leucocephala* and *C. cajan* did better than those fed *S. sesban*, which in turn performed better than the control group which was dependent on grazing. In their study Karachi and Zengo (1998) also reported that goats fed any of the three browses when afflicted with trypanosomiasis (animal sleeping sickness) at the height of the wet season in December 1991 were more resilient than the control group. All four groups lost mass, but the browse-fed groups recovered more quickly than the control group which continued to lose mass for a further two months (Karachi and Zengo, 1998). In their study the effects of trypanosomiasis were more severe and prolonged in the control group than among the browse-supplemented goats, a situation which seems to match the responses of the two groups of lambs in this study to the period of unusually cold conditions (Fig. 4.28).

These results are not consistent with the final contrasts in mass between the browse and control groups as established by Karachi and Zengo (1998). Their study showed significant differences between the mass of browse-fed groups and the control group at the completion of their trial. For example, in their 1991/1992 trial the respective gains were 31.8, 31.5, 24.5 and 19.9 g/head/day day for *C. cajan, L. leucocephala, S. sesban* and the control respectively. However, their control group was dependent on the veldt, which probably provided less nutrition than bran. Similarly the goats in their trial were penned overnight, during which they fed on the browse, and were then released to graze during the day so that more of their energy was spent grazing

than in the continuously-penned trial group of this study. This explains the much higher gains of 83.95 and 102 g/lamb/day for the control and the browse groups in this study. In the study of Shenkoru and Mekonnen (1994) in Debre Zeit, Ethiopia, the increase in mass gain was related to increases in the proportion of browse fed to the different groups. Over the 90 days of their trial, three groups of penned-sheep, fed *Leucaena* as a crude protein supplement at proportions 8, 18 and 24% to *Cicer arietinum* L. (chick pea haulm), experienced mass gains of 72, 73 and 87 g/head/day. This compares well with the results of this study with the 30% *Leucaena* leading to a mean mass gain of 103 g/head/day for the browse group.

5.5 FINANCIAL ANALYSIS OF THE TWO FEEDING REGIMES

The economic analysis of this study should be viewed in the context that the fodder used in this trial was harvested from trees that had been established six years previously. The actual planting cost was P800.00 at the time and the trees were purchased at P3 300.00 from the nursery of the FAB. Over the six years the fodder from trees had been harvested and used to meet the protein needs of the farm, either processed or as a raw crop. Further, in the total harvest of the final year only a small fraction of the fodder was used to feed the lambs in the trial. The extra value of P120.40 for the browse group is based on the fraction of the cost of harvesting and weeding for that year only. The total yield in leaf and pod mass was 3.8 tonnes, only a fraction of which was used.

An analysis of the costs and benefits of the two feed system is presented in Table 5.3. It is based on the assumption that lambs were purchased at P90 each, which is the figure used by the Botswana College of Agriculture for lambs of the same age. (However, the Botswana Unified Revenue Service allows lambs to be priced at either P10 for subsistence and P45 for commercial farmers due to high mortality among lambs). The sale of sheep is based on their live mass.

Table 5.3 Cost-benefit analysis of the feeding regime in Botswana Pula.

Item	Browse Group	Control Group
Sales Revenue	4 760.00	4 435.00
Variable Costs		
Initial cost of sheep	720.00	720.00
Sales value at the end of the feeding trial	4 760.00	4 435.00
Price/kg for fattened sheep	20.00	20.00
Vet remedies:		
Pasturella	3.80	3.80
Pulpivax	12.00	12.0
Dewormer	9.60	9.60
Water	36.00	36.00
Grass hay at P12.00/20kg bale	350.00	620.00
Supplement Browse	120.40	
Bran	130.00	130.00
Total variable costs	1381.80	1 531.40
Gross margin	3378.20	2 903.80
Gross margin/sheep	422.28	362.98
Fixed Costs		
Rent	15.00	15.00
Labour	275.00	275.00
Total fixed costs	290.00	290.00
Net farm income	3088.20	2 613.80
Net income/ sheep	386.03	326.73

Botswana Pula (P1 = $0.171)

Comparison of the benefits of the two feeds in Pula monetary terms is presented in Table 5.3. It is evident that an increase in the net income per animal of more than 18.5% can be realised through browse-feeding and can make an important contribution to farmer's income. On the basis of these results, it is clear that browse can provide adequate nutrition for lambs and decrease lamb mortality associated with adverse environmental conditions.

Through tree growing on-farm, farmers could make available to themselves a reliable source of protein. This is particularly important as wheat bran, which is a possible supplement, is only available from a limited number of sites and often involves considerable transport costs if farmers are to access it. On the other hand, sorghum bran, which is readily available, is susceptible to frequent price increases. These stem from the fact that Botswana is not self-

sufficient in sorghum production and prices vary according to the fluctuations in supply and demand in those countries, principally South Africa, which are in a position to export the cereal. Prices have also risen as result of increases in fuel costs and are always susceptible to the perception of vendors that when the range is degraded farmers have little option but to purchase bran at the price stipulated. Consequently the price of sorghum bran has increased by 56% between 2004 and 2006, while that of wheat bran, which most farmers prefer, has risen by 98%.

The price of *M. sativa*, which is popular and commonly used as a commercial feed, has risen by approximately 65% between 2004 and 2006. This price largely depends on the availability of grazing. Of concern to farmers seeking to purchase *M. sativa* is the absence of regulations to standardise the mass of bales, which leaves farmers vulnerable to sharp practice on the part of suppliers.

Similarly, because of its low crude protein content, buffel grass can be substituted in part by browse to good effect. Its cost, like that of bran and *M. sativa,* tends to increase substantially during the dry season. Increases of between 100 and 150% in the cost of a 20 kg bale may occur, depending on the condition of the range in any one year. Its price is often comparable to that of the more protein-rich *M. sativa*, with which it shares the lack of standardisation with respect to bale weight. Tree growing on-farm will bring more effective management to farmers and reduce the costs of production. By the same token they will have available a reliable source of good quality feed which is rich in protein.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 The high survival and growth rates of *A. galpinii, L. leucocephala* and *L. diversifolia* trees in this study demonstrate the great potential of tree growing on-farm for sustainable agriculture in eastern Botswana.

6.1.2 The poor performance of *F. albida* four years after planting suggests that, despite its high protein content, high digestibility and low tannin content, caution should be exercised in recommending it for on-farm planting in much of Botswana. These results are consistent with the generally poor performance of the species elsewhere in arid zones. However, species trials may be worthwhile in Tati East District and Tutume Sub-District where the water table is frequently higher than in much of the country. Here *F. albida* is indigenous, occurring frequently in fields and along drainage lines .

6.1.3 *A. galpinii* is an excellent species to plant for shade on-farm and can also be grown at high density to provide poles as a medium term product, at the age of 5 years, when it can be thinned to yield poles, leaving the remainder of the trees to provide shade.

6.1.4 The good survival rates and high leaf and pod productivity of *L. diversifolia* and *L. leucocephala* suggest that these species have considerable potential in eastern Botswana, despite soil acidity and low and erratic rainfall, since wet season growth can provide protein to supplement livestock feed. *L. diversifolia,* which is less seedy, can be planted for fodder in wetter areas such as the Chobe and Ngamiland Districts.

6.1.5 Yields of agroforestry products in high density stands at 5 x 5 m, suggest that closer spacing of both *Leucaena* species could increase yields per hectare of browse and should be explored for wetter areas such as the Chobe and Ngamiland Districts to increase the availability of feed. However, for most of eastern Botswana where rainfall is similar to

Malotwana, low density spacing of e.g. 8.3 x 5 m is preferable to reduce competition for soil water.

6.1.6 Although *L. diversifolia* was consistently lower in both leaf and pod production than *L. leucocephala*, in both drought conditions and in years of plentiful rainfall, it should be adopted for planting in eastern Botswana in order to diversify sources of tree fodder.

6.1.7 Leaves of all four species and pods of the exotic species far exceeded the minimum required crude protein for livestock and were comparable in content to the commonly-used protein source, *M. sativa,* (lucerne)and higher than sorghum bran.

6.1.8 Pods of exotic species, although more tanniferous, have a higher protein content and dry more easily than the leaves, and could be part of dry season fodder on-farm. They can be fed at a ratio of 2:1 to the leaves, as 30% of the total feed, without detrimental effects on sheep, while contributing to higher growth rates and better health compared to sorghum bran.

6.1.9 Comparison of the growth of lambs, fed browse at a ratio of 2:1 pods to leaves from weaning to sale, demonstrates a superior mass gain to those fed sorghum bran and the former were more resilient during cold periods.

6.1.10 Growing trees on-farm can contribute to sustainable agriculture through the provision of protein, which is a major limiting factor to animal production. Through such a practice purchased supplements such as *M. sativa* can be reduced, limiting livestock losses and alleviating poverty by improving nutrition and reducing livestock mortality among resource-poor farmers.

6.2 RECOMMENDATIONS

6.2.1 On-farm tree growing to facilitate sustainable livestock should be encouraged and supported nationally. Such on-farm planting should involve indigenous trees for shade and research into their ability to reduce erosion. Additionally, complementary exotic trees, such as *L. diversifolia* and *L. leucocephala* can meet immediate fodder needs.

6.2.2 There is need to explore the most effective spacing of *A. galpinii* that will provide shade while allowing the cultivation of understorey crops, such as grasses and *L. purpureus*, so that the most supportive silvopastoral practice is identified. Such research could be carried out in eastern Botswana after farmers' preferences for tree density and fodder needs have been investigated.

6.2.3 There is need to explore the production of *A. galpinii* at contrasted spacings for different agroforestry products such as browse, pods and poles which are relevant to the diversification of farm income.

6.2.4 Further research on *F. albida*, which has a high protein content, is highly digestible, and has a low condensed tannin content, should be restricted to sites which closely match those where it occurs naturally in Botswana. Such sites could include Tutume Sub-District and Tati East District where the species is indigenous and occurs in fields naturally.

6.2.5 Research into *L. diversifolia* and *L. leucocephala* should be pursued simultaneously to diversify fodder sources while ensuring fodder will be available even if the psyllid, *Heteropsylla cubana,* that affects the more productive *L. leucocephala*, reaches the country.

6.2.6 The performance of both *L. diversifolia* and *L. leucocephala* on a per hectare basis should be evaluated against those of other fodder plants, such as *L. purpureus,* under the same watering regime.

6.2.7 Investigation of the harvesting time for the pods of *Leucaena* spp. is needed so that seeds are both retained in pods and are immature at harvest to ensure that the protein content is maintained at a high level and that self-seeding on-farm or the range is avoided.

6.2.8 Comparative studies of the crude protein contents of the leaves and pods of all four species are needed. Such studies should be followed by feed trials comparing the growth of animals fed on pods with those fed on leaves. The results of such studies will form the basis for the respective roles of leaves and pods in feeding strategies.

6.2.9 Further studies are required to compare the growth rates of livestock utilising other feeds, especially *M. sativa*, *L. purpureus* and sorghum bran, to validate the relative contribution of browse feed.

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APPENDIX 1: MAX. AND MIN. TEMPERATURES RECORDED AT DAR. SEPT. TO DEC. 2001

Table 3.1 Max. and Min.Temperatures Recorded at Sebele Research Station Sept. to Dec. 31 2001

		Air temparature (°C)						
	Sept		Oct		Nov		Dec	
Day	Max	Min	Max	Min	Max	Min	Max	Min
1	23.8	4.7	33.0	12.2	29.5	12.2	30.4	17.4
2	27.6	2.6	33.8	14.7	29.8	16.0	31.6	16.8
3	28.9	6.4	30.0	15.1	32.2	16.0	32.4	16.9
4	32.6	9.5	31.5	11.2	29.6	16.2	26.0	18.7
5	33.6	7.3	34.4	11.1	34.4	12.4	27.4	17.2
6	28.3	9.0	34.5	15.7	29.4	18.4	32.0	16.9
7	29.4	5.9	34.7	12.6	34.7	18.2	29.9	17.6
8	28.7	9.1	30.1	17.4	20.2	17.6	29.7	16.6
9	31.6	10.2	27.1	13.9	20.0	13.6	31.2	18.2
10	35.7	11.2	32.6	12.8	24.8	15.9	31.7	19.6
11	32.0	16.4	34.2	15.2	29.4	15.2	31.6	19.9
12	26.4	12.3	34.4	15.9	30.3	16.2	27.6	17.2
13	24.2	9.4	36.2	16.7	25.6	15.2	25.6	18.3
14	15.7	6.0	31.6	16.1	28.9	19.9	26.9	19.6
15	15.7	11.3	33.3	14.7	30.1	16.8	30.0	16.0
16	25.3	10.4	33.4	17.5	26.4	17.3	32.0	17.3
17	30.0	8.0	33.0	19.5	19.4	14.7	35.0	18.9
18	29.1	12.9	32.9	17.7	26.2	15.4	34.7	18.8
19	27.2	16.6	33.2	14.4	27.5	16.9	35.4	19.9
20	20.3	11.7	30.5	13.9	29.9	17.2	31.5	15.5
21	28.4	13.4	24.8	14.7	31.2	18.0	31.6	14.7
22	29.0	11.8	30.8	14.0	32.7	14.0	32.7	15.9
23	31.8	12.7	34.0	17.0	30.3	18.2	31.4	19.9
24	35.5	13.9	33.6	19.8	32.5	17.3	32.0	17.2
25	33.2	15.0	31.0	19.5	32.0	18.8	33.0	18.7
26	33.8	10.7	25.0	19.2	26.5	18.9	30.3	14.7
27	25.6	16.4	23.2	18.5	28.0	18.4	27.9	17.5
28	27.7	9.4	29.7	17.4	20.0	16.7	30.1	16.2
29	29.4	10.7	29.9	16.5	21.8	16.2	30.3	15.3
30	31.8	12.5	31.2	14.9	26.3	18.0	32.2	16.7
31			30.2	16.7			31.6	17.4

APPENDIX 2: MONTHLY RAINFALL RECORDED AT THE TRIAL SITE

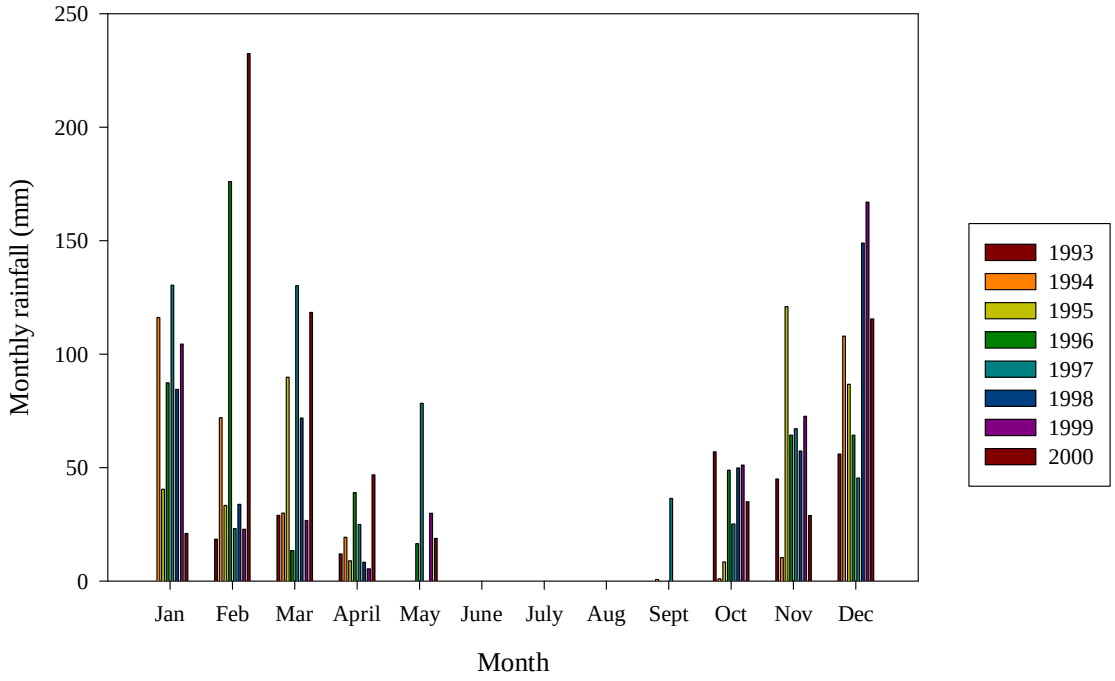

Fig. 1 Monthly rainfall recorded at the trial site for the duration of the study

Table 1 Seasonal total rainfall for the study period

Season	1993/1994	1994/1995	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000
Total Rainfall (mm)	395.4	412.6	548.4	464.4	372.4	445.2	728.1

APPENDIX 3: SUMMARY OF SOIL ANALYSIS OF THE TRIAL SITE

Table 1 Summary of Soil of the Site at Different Depths

Block	Description	pH ($CaCl_2$)	K	Exchangeable Bases me %			Cec me%	C (%)	P ppm
				Na	Ca	Mg			
1 30 cm	Sandy very weak medium to coarse. Common fine pores in first 32 cm layer few fine roots 32-70 cm brown soil, non calcareous at 70 –130 cm few medium root	4.07c	0.082b	0.03a	0.257a	0.199ab	1.523a	0.157a	1.842a
60 cm		4.12c	0.083b	0.059a	0.292a	0.313ab	1.54a	0.117a	1.943a
100 cm		4.13c	0.077b	0.037a	0.220b	0.317bc	1.67ab	0.072a	1.522ab
2 30 cm		4.15bc	0.088b	0.038a	0.317a	0.147b	1.829a	0.142ab	2.039a
60 cm		4.17bc	0.081b	0.038a	0.327a	0.209b	1.451a	0.097a	1.853a
100 cm		4.15c	0.081b	0.041a	0.362a	0.236c	1.481b	0.072a	1.741a
3 30 cm		4.28a	0.102ab	0.029a	0.37a	0.269a	1.704a	0.104c	0.863b
60 cm		4.36a	0.08b	0.028a	0.407a	0.408a	1.727a	0.097a	0.794b
100 cm		4.41a	0.107a	0.029a	0.473a	0.534a	1.997a	0.070a	0.814b
4 30 cm		4.20ab	0.08b	0.027a	0.423a	0.216ab	1.654a	0.117bc	1.079ab
60 cm		4.25ab	0.083b	0.024a	0.407a	0.372a	1.838a	0.100a	1.014b
100 cm		4.29b	0.085b	0.027a	0.419a	0.564a	1.907ab	0.087a	0.8317b
5 30 cm		4.18ab	0.122a	0.106a	0.362a	0.220ab	1.653a	0.128abc	1.165ab
60 cm		4.26ab	0.12a	0.104a	0.363a	0.338a	1.78a	0.097a	1.346ab
100 cm		4.25bc	0.116ab	0.019a	0.346ab	0.476ab	1.852ab	0.085a	1.202ab

Nitrogen was found to read nil using Kjeldahl method. Soil description from FAO and analysis from Department of Agricultural Research supported by check run to confirm single run by the laboratory of 180 samples. Two samples per block for each soil depth was checked for all components of the mineral and organic matter. The results of the check were consistent with the results for the main data analysis.

APPENDIX 4: MEAN PARAMETERS OF INDIGENOUS TREES AND ANOVA SUMMARY TABLES

Table 1 Performance of *A. galpinii* and *F. albida* at different spacing

Year Age	Species	Spacing	N	Crown diameter	dbhno	Mean dbh (cm)	Height (m)	Stem Volume Index
1994	*A.galpinii*	5.0	20	1.98 ± 0.14a	2.00 ± 0.18a		1.47 ± 0.10a	
0.5		6.3	20	1.90 ± 0.14a	1.95 ± 0.18a		1.63 ± 0.10a	
		8.3	20	2.02 ± 0.14a	2.35 ± 0.18a		1.51 ± 0.10a	
	Mean		60	1.97 ± 0.08a	2.10 ± 0.10a		1.53 ± 0.06A	
	F. albida	5.0	20	1.77 ± 0.14ba	1.45 ± 0.18a		1.28 ± 0.10a	
		6.3	20	1.67 ± 0.14b	1.15 ± 0.18a		1.11 ± 0.10a	
		8.3	20	2.07 ± 0.14a	1.45 ± 0.18a		1.32 ± 0.10a	
	Mean		60	1.83 ± 0.08a	1.35 ± 0.08b		1.24 ± 0.06B	
1996	*A.galpinii*	5.0	20	3.52 ± 0.19a	2.00 ± 0.18a	3.47 ± 0.23a	2.85 ± 0.13a	70.06 ± 10.86 a
2.5		6.3	20	4.27 ± 0.19a	1.95 ± 0.18a	3.58 ± 0.23a	3.03 ± 0.13a	79.46 ± 10.86 a
		8.3	20	4.08 ± 0.19a	2.45 ± 0.18a	3.85 ± 0.23a	3.02 ± 0.13a	112.77 ± 10.86 a
	Mean		60	3.95 ± 0.11A	2.10 ± 0.10	3.66 ± 0.13A	2.97 ± 0.07A	87.43 ± 6.26 A
	F. albida	5.0	20	3.0 ± 0.19a	1.45 ± 0.18a	3.09 ± 0.23a	2.58 ± 0.13a	36.57 ± 10.86a
		6.3	20	2.88 ± 0.19a	1.15 ± 0.18a	3.23 ± 0.23a	2.49 ± 0.13a	33.01 ± 10.85a
		8.3	20	2.78 ± 0.19a	1.45 ± 0.18a	3.35 ± 0.23a	2.58 ± 0.13a	42.16 ± 10.85a
	Mean		60	2.89± 0.11B	1.35 ± 0.10	3.22 ± 0.13B	2.55 ± 0.07B	37.24 ± 6.27B
1998	*A.galpinii*	5.0	20	4.98 ± 0.24a	2.15 ± 0.19a	6.70 ± 0.41b	3.84 ± 0.18a	467.85 ± 69.74a
4.5		6.3	20	5.05 ± 0.24a	1.95 ± 0.19a	7.31 ± 0.41ba	4.23 ± 0.18a	466.8 ± 69.74a
		8.3	20	5.12 ± 0.24a	2.40 ± 0.19a	7.98 ± 0.41a	3.90 ± 0.18a	677.00 ± 69.74a
	Mean		60	5.05 ± 0.14A	2.17 ± 0.11	7.40 ± 0.24A	4.00 ± 0.10B	537.24 ± 40.26A
1998	*F. albida*	5.0	20	2.80 ± 0.24a	1.60 ± 0.19a	5.51 ± 0.41b	4.17 ± 0.18a	205.42 ± 69.74a
		6.3	20	2.79 ± 0.24a	1.20 ± 0.19b	5.86 ± 0.41ba	4.53 ± 0.18a	217.49 ± 69.74a
		8.3	20	2.65 ± 0.24a	1.20 ± 0.19b	6.41 ± 0.41a	4.39 ± 0.18a	244.31 ± 69.75a
	Mean		60	2.75 ± 0.14B	1.33 ± 0.11	5.93 ± 0.24B	4.36 ± 0.10A	222.41 ± 40.26B
2000	*A.galpinii*	5.0	20	5.86 ± 0.24b	2.45 ± 0.18a	10.38 ± 0.64b	4.99 ± 0.25a	1441.16 ± 215.84b
6.5		6.3	20	5.83 ± 0.24b	2.30 ± 0.18a	10.57 ± 0.64b	4.65 ± 0.25a	1223.92 ± 215.84b
		8.3	20	6.56 ± 0.25a	2.45 ± 0.18a	12.48 ± 0.64a	5.13 ± 0.25a	2193.93 ± 215.84a
	Mean		60	6.08 ± 0.14A	2.40 ± 0.10	11.14 ± 0.37a	4.92 ± 0.15A	1619.67 ± 124.61A
2000	*F.albida*	5.0	14	2.21 ± 0.24	1.30 ± 0.18a	1.99 ± 0.78b	2.19 ± 0.25a	15.95 ± 264.19b
		6.3	13	2.90 ± 0.28	0.80 ± 0.18b	4.91 ± 0.82b	2.97 ± 0.29a	168.38 ± 276.93b
		8.3	13	2.75 ± 0.26	1.00 ± 0.18a	6.05 ± 0.83a	3.10 ± 0.27a	282.15 ± 281.83a
	Mean		40	2.63 ± 0.15A	1.03 ± 0.10	4.31± 0.48B	2.75 ± 0.16B	155.49 ± 162.39B

Cd = crown diameter (m). Dbhno = number of diameters. Mdbh mean diameter at breast height (cm). Mdbh mean diameter at breast height square (cm^2). Ht = height (m). Svi = Stem Volume index. Means followed by different letter down the column in each year are significantly different among spacing $p \leq 0.05$

Table 2 Analysis of variance - crown width as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1994 (0.5)	Block	4	3.54336167	0.88584042	2.17	0.0766ns
	Species	1	0.54136333	0.54136333	1.33	0.2515ns
	Spacing	2	1.42407167	0.71203583	1.75	0.1790ns
	Species*Spacing	2	0.48407167	0.24203583	0.59	0.5538ns
	Error	110	44.81676833	0.40742517		
1996 (2.5)	Block	4	3.89282833	0.97320708	1.34	0.2610ns
	Species	1	34.2294083	34.22940083	47.00	<.0001***
	Spacing	2	2.01395167	1.00697583	1.38	0.2552ns
	Species*Spacing	2	4.63870167	2.31935083	3.18	0.0452*
	Error	110	80.1084167	0.7282583		
1998 (4.5)	Block	4	24.5641667	6.1410417	5.12	0.0008***
	Species	1	159.0451875	159.0451875	132.65	<.0001***
	Spacing	2	0.0307917	0.0153958	0.01	0.9872ns
	Species*Spacing	2	0.4188750	0.2094375	0.17	0.8400ns
	Error	110	131.8929583	1.1990269		
2000 (6.5)	Block	4	15.7010940	3.9252735	3.27	0.0144*
	Species	1	334.4488974	334.4488974	278.44	<.0001***
	Spacing	2	7.9397777	3.9698888	3.31	0.0406*
	Species*Spacing	2	3.7205655	1.8602828	1.55	0.2174ns
	Error	104	124.9211108	1.2011645		

ns = not significant p>0.05, *significant p≤0.05; ***highly significant at p≤0.001

Table 3 Analysis of variance - height as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p- value
1994 (0.5)	Block	4	0.61666667	0.15416667	0.73	0.5719ns
	Species	1	2.64924083	2.64924083	12.58	0.0006***
	Spacing	2	0.04274000	0.02137000	0.10	0.9036ns
	Species*Spacing	2	0.73490667	0.36745333	1.75	0.1794ns
	Error	110	23.16025833	0.21054780		
1996 (2.5)	Block	4	2.33826333	0.58456583	1.83	0.1282ns
	Species	1	5.25845333	5.25845333	16.46	0<0001***
	Spacing	2	0.14718167	0.07359083	0.23	0.7947ns
	Species*Spacing	2	0.37198167	0.18599083	0.58	0.5604ns
	Error	110	35.14786667	0.31952606		
1998 (4.5)	Block	4	19.79144667	4.94786167	7.89	<.0001***
	Species	1	4.16268750	4.16268750	6.64	0.0113*
	Spacing	2	2.88925167	1.44462583	2.30	0.1046ns
	Species*Spacing	2	0.19176500	0.09588250	0.15	0.8583ns
	Error	110	68.95390833	0.62685371		
2000 (6.5)	Block	4	3.5002176	0.8750544	0.67	0.6123ns
	Species	1	132.1042386	132.1042386	101.56	<.0001***
	Spacing	2	5.3947928	2.6973964	2.07	0.1309ns
	Species*Spacing	2	6.1794851	3.0897425	2.38	0.0980ns
	Error	104	135.2725706	1.3006978		

ns = not significant p>0.05; * significant p≤0.05; ***highly significant at p≤0.01

Table 4 Analysis of variance - diameter at breast height as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	27.22946167	6.80736542	6.61	<.0001***
	Species	1	5.08408333	5.08408333	4.94	0.0283*
	Spacing	2	2.02932167	1.01466083	0.99	0.3765ns
	Species*Spacing	2	0.12137167	0.6068583	0.06	0.9428ns
	Error	110	113.2355483	1.0294141		
1998 (4.5)	Block	4	73.42388833	18.35597208	5.38	0.0005***
	Species	1	64.63604083	64.63604083	18.95	<.0001***
	Spacing	2	20.09504667	10.04752333	2.95	0.0567ns
	Species*Spacing	2	0.18114667	0.09057333	0.03	0.9738ns
	Error	110	375.2460367	3.4113276		
2000 (6.5)	Block	4	11.306981	2.826745	0.35	0.8448ns
	Species	1	1037.685148	1037.65148	127.74	<.0001***
	Spacing	2	146.866930	73.433465	9.04	0.0003***
	Species*Spacing	2	31.345498	15.672749	1.93	0.1513ns
	Error	89	722.982532	8.123399		

ns = not significant p>0.05; *significant p≤0.05; ***highly significant at p≤0.001

Table 5 Analysis of variance - stem volume index as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	47609.03906	11902.25976	5.05	0.0009***
	Species	1	75555.52490	75555.52490	32.07	<.0001***
	Spacing	2	13898.39220	6949.19610	2.95	0.0565ns
	Species*Spacing	2	7098.46211	3549.23106	1.51	0.2262ns
	Error	110	259126.9558	2355.6996		
1998 (4.5)	Block	4	1742384.246	435596.061	4.48	0.0022***
	Species	1	2973581.943	2973581.943	30.57	<.0001***
	Spacing	2	392646.598	196323.299	2.02	0.1378ns
	Species*Spacing	2	209207.703	104603.851	1.08	0.3447ns
	Error	110	10699281.33	97266.19		
2000 (6.5)	Block	4	6739133.30	1684783.32	1.81	0.1343ns
	Species	1	47671649.09	47671649.09	51.16	<.0001***
	Spacing	2	5617023.62	2808511.81	3.01	0.0541ns
	Species*Spacing	2	2806234.08	1403117.04	1.51	0.2274ns
	Error	89	82925416.2	931746.2		

ns = not significant p>0.05; ***highly significant at p≤0.01

APPENDIX 5: MEAN PARAMETER OF EXOTIC TREES, AND ANOVA SUMMARY TABLES

Table 1 Mean annual data per tree for parameters measured- Exotic Trees

Species	Year	Spacing (m)	Stem number	Crown diameter (m)	Stem diameter at 50 cm (cm)	Height (m)	Stem volume index
L. diversifolia	1994	5	1.55 ± 0.15a	1.50 ±. 0.10a		0.87 ± 0.07a	
		6.3	1.60 ± 0.15a	1.45 ±. 0.10a		0.94 ± 0.07a	
		8.3	1.65 ± 0.15a	1.66 ±. 0.10a		1.01 ± 0.07a	
		Mean	1.60 ± 0.85B	1.53 ± 0.059A		0.94 ± 0.05A	
L. leucocephala	1994	5	2.00 ± 0.15a	1.73 ± 0.10a		1.02 ± 0.07a	
		6.3	2.30 ± 0.15a	1.59 ±. 0.10a		1.00 ± 0.07a	
		8.3	1.85 ± 0.15a	1.77 ±. 0.13a		1.11 ± 0.07a	
		Mean	2.05 ± 0.85A	1.69 ± 0.059A		1.04 ± 0.05A	
L. diversifolia	1995	5.0	3.05 ± 0.33a	2.18 ±. 0.12a	2.36 ± 0.139a	2.84 ± 0.11a	51.10 ± 8.71a
		6.3	2.90 ± 0.33a	2.08 ±. 0.12a	2.35 ± 0.139a	2.89 ± 0.11a	47.71 ± 8.71a
		8.3	3.05 ± .33a	2.02 ±. 0.12a	2.29 ± 0.139a	3.10 ± 0.11a	57.10 ± 8.71a
		Mean	3.02 ± 0.19A	2.09 ± 0.07A	2.33 ± 0.08A	2.93 ± 0.06A	63.68 ± 6.26A
L. leucocephala	1995	5.0	3.00 ± 0.33a	2.11 ± 0.12a	2.22 ± 0.139a	2.87 ± 0.11a	53.26 ± 8.71a
		6.3	3.9 ± 0.33a	2.26 ± .0.12a	2.17 ± 0.139a	2.88 ± 0.11a	53.18 ± 8.71a
		8.3	2.95 ±. 0.33a	2.17 ± .0.12a	2.44 ± 0.139a	2.92 ± 0.1a1	68.06 ± 8.71a
		Mean	3.28 ± 0.19A	2.18 ± 0.07A	2.28 ± 0.08A	2.89 ± 0.06A	58.34 ± 6.21A
L. diversifolia	1996	5.0	3.40 ±. 41a	2.87 ± 0.19a	3.00 ± 0.21b	3.12 ± 0.13a	105.32 ± 35.64a
		6.3	3.20 ± 0.41a	2.97 ± 0.19a	3.79 ± 0.21a	3.24 ± 0.13a	193.26 ± 35.64a
		8.3	3.10 ± 0.41a	2.90 ± 0.29a	3.39 ± 0.21ba	3.46 ± 0.13a	140.11 ± 35.64a
		Mean	3.17 ± 0.24A	2.9 ± 0.12A	3.39 ± 0.12	3.25 ± 0.08A	114.60 ± 16.75
L.. leucocephala	1996	5.0	3.85 ± 0.41a	2.60 ± 0.19a	3.10 ± 0.21a	3.25 ± 0.13a	152.69 ± 35.64a
		6.3	4.15 ± 0.41a	2.77 ± 0.19a	3.36 ± 0.21a	3.49 ± 0.13a	170.27 ± 35.64a
		8.3	3.45 ± 0.42a	2.67 ± 0.19a	3.36 ± 0.21a	3.25 ± 0.13a	171.44 ± 36.60a
		Mean	3.82 ± 0.24A	2.68 ± 0.11A	3.27 ± 0.12	3.33 ± 0.07A	144.88 ± 16.75
L .diversifolia	1997	5.0	7.30 ± 0.80a	2.04 ± 0.16b	1.82 ± 0.15b	1.69 ± 0.11a	61.44 ± 17.71b
		6.3	7.15 ± 0.80a	2.31 ± 0.16ba	2.31 ± 0.15a	1.93 ± 0.11a	95.04 ± 17.71ba
		8.3	6.62 ± 0.80a	2.45 ± 0.18a	2.53 ± 0.17a	1.84 ± 0.12a	126.00 ± 20.19a
		Mean	7.02 ± 0.48A	2.28 ± 0.09A	2.15 ± 0.09A	1.82 ± 0.06A	94.16 ± 10.22
L.. leucocephala	1997	5.0	8.15 ± 0.8a	2.17 ± 0.16b	1.91 ± 0.15b	1.69 ± 0.11a	72.74 ± 17.71b
		6.3	7.8 ± 0.80a	2.38 ± 0.16ba	2.24 ± 0.15a	1.94 ± 0.11a	78.06 ± 17.71ba
		8.3	8.20± 0.80a	2.59 ± 0.16a	2.29 ± 0.15a	1.79 ± 0.11a	111.92 ± 17.71a
		Mean	8.05 ± 0.46A	2.38 ± 0.09A	2.22 ± 0.09A	1.81 ± 0.06A	87.57 ± 10.22
L.. diversifolia	1998	5.0	6.60 ± 0.90a	2.64 ± 0.22b	2.46 ± 0.204a	2.99 ± 0.18a	192.28 ± 48.61a
		6.3	7.15 ± 0.79a	3.05 ± 0.23ab	2.91 ± 0.204a	3.27 ± 0.18a	262.98 ± 48.61a
		8.3	7.70 ± 0.79a	3.54 ± 0.26a	2.68 ± 0.204a	3.11 ± 0.18a	294.74 ± 48.61a
			7.15 ± 0.48A	3.08 ± 0.14	2.68 ± 0.12	3.10 ± 0.11	236.87 ± 34.75
L.. leucocephala	1998	5.0	8.15 ± 0.81a	2.84 ± 0.23b	2.25 ± 0.204a	3.00 ± 0.18b	182.67 ± 48.61a
		6.3	7.8 ± 0.81a	3.17 ± 0.23ab	2.71 ± 0.204a	3.43 ± 0.18a	205.19 ± 48.61a
		8.3	8.20 ± 0.81a	3.27 ± 0.23a	2.58 ± 0.204a	3.31 ± 0.18ba	261.65 ± 48.61a
		Mean	8.05± 0.45A	3.09 ± 0.13	2.51 ± 0.12	3.25 ± 0.10	207.00 ± 33.14
L.. diversifolia	1999	5.0	5.65 ± 1.02a	1.62 ± 0.15a	1.23 ± 0.05a	1.54 ± 0.12a	17.63 ± 9.07a
		6.3	5.69 ± 1.11a	1.84 ± 0.16a	1.28 ± 0.05a	1.59 ± 0.12a	21.27 ± 9.37a
		8.3	8.49 ± 1.18a	2.13 ± 0.16a	1.43 ± 0.06a	2.07 ± 0.13a	64.60 ± 10.04a
		Mean	6.61 ± 1.10	1.87 ± 0.09	1.31 ± 0.03	1.79 ± 0.07	32.64 ± 5.12
L.. leucocephala	1999	5.0	8.34± 1.07a	2.08 ± 0.15a	1.30 ± 0.05a	2.13 ± 0.12a	40.85 ± 9.07a
		6.3	9.50 ± 1.02a	2.24 ± 0.15a	1.41 ± 0.05a	2.23 ± 0.12a	50.96 ± 8.82a
		8.3	8.58 ± 1.11a	1.98 ± 0.15a	1.26 ± 0.05a	2.12 ± 0.12a	53.94 ± 8.83a
		Mean	8.81 ± 1.06	2.06 ± 0.09	1.32 ± 0.03	2.16 ± 0.07	45.82 ± 5.02
L. .diversifolia	2000	5.0	9.70 ± 1.05a	3.63 ± 0.20a	2.10 ± 0.100b	3.06 ± 0.16a	166.72 ± 47.68b
		6.3	9.40 ± 1.05a	3.89 ± 0.20a	2.26 ± 0.10b	3.30 ± 0.16a	200.31 ± 47.68b
		8.3	12.05 ± 1.05a	4.35 ± 0.22a	2.64±0.10a	3.73 ± 0.18 a	361.66 ± 47.68a
		Mean	10.41 ± 0.63B	3.93 ± 0.12	2.33 ± 0.06	3.50 ± 0.09	219.48 ± 32.56
L.. leucocephala	2000	5.0	11.80 ± 1.05a	4.23 ± 0.20a	2.22 ± 0.10a	3.51 ± 0.16a	271.48 ± 47.68b
		6.3	13.10 ± 1.05a	4.37 ± 0.20a	2.15 ± 0.100b	3.54 ± 0.16a	229.08 ± 47.68b
		8.3	13.70 ± 1.05a	4.09 ± 0.20a	2.24 ± 0.100a	3.45 ± 0.18a	305.22 ± 47.68a
		Mean	12.86 ± 0.12A	4.23 ± 0.13A	2.20 ± 0.06A	3.33 ± 0.10A	239.28 ± 31.36A

Spp = species, Stone = stem number, Std. = stem diameter at 50cm(cm^2), Cd = Crown diameter, Ht = height (m), Svi = Stem Volume index, FW = leaf weight (kg) Wood mass (kg) Twt = Total Wood mass (kg), Pods = dry pods weight (kg) of exotic trees over time period of study

Means followed by different letters down the colum in each year are significantly different among spacing $p \leq 0.05$

Table 2 Analysis of variance - Crown width as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1994 (0.5)	Block	4	5.76019500	1.44004875	6.94	<.0001***
	Species	1	0.76320750	0.76320750	3.68	0.0577ns
	Spacing	2	0.78416167	0.39208083	1.89	0.1559ns
	Species*Spacing	2	0.08634500	0.04317250	0.21	0.8124ns
	Error	110	22.81869000	0.20744264		
1995 (1.5)	Block	4	18.24604167	4.56151042	15.90	<.0001***
	Species	1	0.22533333	0.22533333	0.79	0.3774ns
	Spacing	2	0.12087500	0.06043750	0.21	0.8104ns
	Spacing*Spacing	2	0.33904167	0.16952083	0.59	0.5556ns
	Error	110	31.5583833	0.28689417		
1996 (2.5)	Block	4	35.7833333	8.94583333	12.09	<.0001***
	Species	1	1.6333333	1.6333333	2.21	0.1401ns
	Spacing	2	0.3875000	0.19375000	0.26	0.7700ns
	Species*Spacing	2	0.02916667	0.01458333	0.02	0.9805ns
	Error	110	81.3666667	0.739670		
1997 (root system 3.5 coppice growth 1)	Block	4	16.2483033	4.06207708	8.60	<.0001***
	Species	1	0.35208333	0.35208333	0.75	0.3897ns
	Spacing	2	3.24450000	1.62225000	3.44	0.0357*
	Species*Spacing	2	0.09816667	0.04908333	0.10	0.9014ns
	Error	110	51.94199167	0.47219992		
1998 (root system 4.5 coppice growth 2)	Block	4	38.76292167	9.69073042	9.20	<.0001***
	Species	1	0.15265333	0.15265333	0.14	0.7041ns
	Spacing	2	7.00454000	3.50227000	3.33	0.0396*
	Species*Spacing	2	0.55840667	0.27920333	0.27	0.7676ns
	Error	110	115.8479583	1.0531633		
1999 (5.5 root coppice growth 1)	Block	4	11.73392103	2.93348026	6.53	<.0001***
	Species	1	1.86010159	1.86010159	4.14	0.0443*
	Spacing	2	0.84203584	0.42101792	0.94	0.3947ns
	Species*Spacing	2	3.09789669	1.54894835	3.45	0.0353*
	Error	108	48.48677341	0.44895161		
2000 (root system 6.5 coppice growth 1)	Block	4	52.63629667	13.15907417	16.29	<.0001***
	Species	1	2.24954083	2.24954083	2.78	0.098ns
	Spacing	2	1.78770667	0.89385333	1.11	0.3344ns
	Species*Spacing	2	4.31160667	2.15580333	2.67	0.0738ns
	Error	110	88.860083	0.8078183		

ns = not significant $p>0.05$; *significant $p\leq0.05$; ***highly significant at $p\leq0.001$

Table 3 Analysis of variance - with height as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1994 (0.5)	Block	4	3.45603833	0.86400958	9.87	<.0001***
	Species	1	0.31314083	0.31314083	3.58	0.0613ns
	Spacing	2	0.29540667	0.14770333	1.69	0.1899ns
	Species*Spacing	2	0.03764667	0.01882333	0.21	0.8069ns
	Error	110	9.63412667	0.08758297		
1995 (1.5)	Block	4	1.22231333	0.30557833	1.30	0.2729ns
	Species	1	0.09747000	0.09747000	0.42	0.5203ns
	Spacing	2	0.55570667	0.27785333	1.19	0.393ns
	Species*Spacing	2	0.23864000	0.11932000	0.51	0.6023ns
	Error	110	25.77106667	0.23428242		
1996 (2.5)	Block	4	1.11302167	0.27825542	0.85	0.4969ns
	Species	1	0.09918750	0.09918750	0.30	0.5833ns
	Spacing	2	0.79012167	0.39506083	1.21	0.3033ns
	Species*Spacing	2	1.1856950	0.59284750	1.81	0.1685ns
	Error	110	39.22105917	0.3275303		
1997 (root system 3.5 coppice growth 1)	Block	4	7.79716667	1.94929167	8.26	<.0001***
	Species	1	0.01875000	0.01875000	0.08	0.7786ns
	Spacing	2	1.27400000	0.63700000	2.70	0.0718ns
	Species*Spacing	2	0.02600000	0.01300000	0.06	0.9465ns
	Error	110	25.97333333	0.23612121		
1998 (root system 4.5 coppice growth 2)	Block	4	18.11156333	4.52789083	7.22	<.0001***
	Species	1	0.43320083	0.43320083	0.69	0.4077ns
	Spacing	2	2.51263167	1.25631583	2.00	0.1398ns
	Species*Spacing	2	0.19585167	0.09792583	0.16	0.8556ns
	Error	110	68.99121167	0.62719283		
1999 (root system 5.5 coppice growth 1)	Block	4	7.88400836	1.97100209	6.46	0.0001***
	Species	1	4.60930474	4.60930474	15.39	0.0002***
	Spacing	2	0.84753635	0.42376818	1.39	0.2536ns
	Species*Spacing	2	1.88406544	0.94203272	3.09	0.0496*
	Error	107	32.62578252	0.30491386		
2000 (root system 6.5 root coppice growth 2)	Block	4	18.85889167	4.71472292	8.89	<.0001***
	Species	1	0.45633333	0.45633333	0.86	0.3557ns
	Spacing	2	2.96292167	1.48146083	2.79	0.0656ns
	Species*Spacing	2	2.32617167	1.16308583	2.19	0.1165ns
	Error	110	58.34619833	0.53041998		

ns = not significant $p>0.05$; *significant $p\leq0.05$; ***highly significant $p\leq0.001$

Table 4 Analysis of variance - stem diameter at (50cm) as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1995 (1.5)	Block	4	15.182625	3.7956625	9.82	<.0001***
	Species	1	0.10384083	0.10384083	0.27	0.6052ns
	Spacing	2	0.22218667	0.11109333	0.29	0.7507ns
	Species*Spacing	2	0.66530667	0.33265333	0.86	0.4256ns
	Error	110	42.50612000	0.38641927		
1996 (2.5)	Block	4	27.99944358	6.99986090	8.20	<.0001***
	Species	1	0.44091601	0.44091601	0.52	0.47379ns
	Spacing	2	5.47381161	2.73690580	3.21	0.0444*
	Species*Spacing	2	1.51849577	0.75924789	0.89	0.4139ns
	Error	110	93.0683146	0.8538377		
1997 (root system 3.5 root coppice growth 1)	Block	4	12.12125333	3.03031333	6.58	<.0001***
	Species	1	0.02821333	0.02821333	0.06	0.8050ns
	Spacing	2	5.29372667	2.64686333	5.75	0.0042***
	Species*Spacing	2	0.22722667	0.11361333	0.25	0.7818ns
	Error	110	50.66881667	0.46062561		
1998 (root system 4.5 Coppice growth 2)	Block	4	23.08084500	5.77021125	6.91	<.0001***
	Species	1	0.84336333	0.84336333	1.01	0.3173ns
	Spacing	2	4.21363167	2.10681583	2.52	0.0850ns
	Species*Spacing	2	0.06098167	0.03049083	0.04	0.9642ns
	Error	110	91.9166150	0.8356056		
1999 (root system 5.5 coppice growth 1)	Block	4	0.77313093	0.19328273	3.75	0.0071***
	Species	1	0.00095707	0.00095707	0.02	0.8919ns
	Spacing	2	0.15444606	0.07722303	1.50	0.2288ns
	Species*Spacing	2	0.43097872	0.21548936	4.18	0.0182*
	Error	93	4.79294928	0.05153709		
2000 (root system 6.5 coppice growth 2)	Block	4	7.73238833	1.93309708	9.54	<.0001***
	Species	1	0.51221333	0.51221333	2.53	0.1147ns
	Spacing	2	1.79301167	0.89650583	4.42	0.0142*
	Species*Spacing	2	1.37636167	0.68818083	3.40	0.0371*
	Error	110	22.29142167	0.20264929		

ns = not significant p>0.05; * significant p≤0.05; ***highly significant at p≤0.001

Table 5 Analysis of variace with stem (coppice shoot) number as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1994 (0.5)	Block	4	2.7833333	0.6958333	1.59	0.1831ns
	Species	1	6.0750000	6.0750000	13.84	0.0003***
	Spacing	2	0.9500000	0.4750000	1.08	0.3423ns
	Species*Spacing	2	1.2500000	0.6250000	1.42	0.2451ns
	Error	110	48.26666667	0.43878788		
1995 (1.5)	Block	4	75.1333333	18.78333333	8.42	<.0001***
	Species	1	2.40833333	2.40833333	1.08	0.3010ns
	Spacing	2	4.01666667	2.00833333	0.90	0.4093ns
	Species*Spacing	2	7.71666667	3.85833333	1.73	0.1821ns
	Error	110	245.3166667	2.2301515		
1996 (2.5)	Block	4	72.21666667	18.05416667	5.32	0.0006***
	Species	1	10.20833333	10.20833333	3.01	0.0858ns
	Spacing	2	3.800000000	1.900000000	0.56	0.5732ns
	Species*Spacing	2	2.06666667	1.033333333	0.30	0.7383ns
	Error	110	373.6333333	3.396667		
1997 (root system 3.5 coppice growth 1)	Block	4	659.5833333	164.8958333	13.21	<.0001***
	Species	1	42.0083333	42.0083333	3.37	0.0692ns
	Spacing	2	6.0666667	3.0333333	0.24	0.7846ns
	Species*Spacing	2	11.4666667	5.7333333	0.46	0.6328ns
	Error	110	1372.666667	12.478788		
1998 (root system 4.5 coppice growth 2)	Block	4	517.4500000	129.3625000	9.87	<.0001***
	Species	1	6.07500000	6.0750000	0.46	0.4973ns
	Spacing	2	7.8000000	3.9000000	0.30	0.7431ns
	Species*Spacing	2	0.8000000	0.4000000	0.03	0.9699ns
	Error	110	1441.200000	13.101818		
1999 (root system 5.5 coppice growth 1)	Block	4	969.6858340	242.4214585	11.48	<.0001***
	Species	1	51.3536319	51.3536319	2.43	0.1219ns
	Spacing	2	103.6478601	51.8239300	2.45	0.0908ns
	Species*Spacing	2	224.2054072	112.1027036	5.31	0.0063***
	Error	107	2259.949460	21.121023		
2000 (root system 6.5 coppice growth 2)	Block	4	439.75000	109.9375000	5.00	0.0010***
	Species	1	185.0083333	185.0083333	8.41	0.0045***
	Spacing	2	98.75000	49.37500000	2.24	0.1108ns
	Species*Spacing	2	23.2166667	11.6083333	0.53	0.5914ns
	Error	110	2419.400000	21.994545		

ns = not significant $p>0.05$, ***highly significant $p\leq0.001$

Table 6 Analysis of variance with stem volume index as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1995 (1.5)	Block	4	106887.0801	26721.7700	17.62	<.0001***
	Species	1	1279.4229	1279.4229	0.84	0.3604ns
	Spacing	2	3154.4579	1577.2290	1.04	0.3570ns
	Species*Spacing	2	497.0515	248.5258	0.16	0.8491ns
	Error	110	166857.8418	1516.8895		
1996 (2.5)	Block	4	722950.4375	180737.6046	7.11	<.0001***
	Species	1	10249.4959	10249.4959	0.40	0.5267ns
	Spacing	2	55679.9784	27839.9892	1.10	0.3380ns
	Species*Spacing	2	27157.4110	13578.7055	0.53	0.5876ns
	Error	109	2769809.966	25411.101		
1997 (root system3.5 coppice growth 1)	Block	4	299871.6143	74967.9056	12.10	<.0001***
	Species	1	57.5745	57.5745	0.01	0.9234ns
	Spacing	2	39005.5214	19502.7607	3.15	0.0468*
	Species*Spacing	2	4125.1586	2062.5793	0.33	0.7175ns
	Error	110	681267.635	6193.342		
1998 (root system 4.5 coppice growth 2)	Block	4	2198037.509	549509.377	11.63	<.0001***
	Species	1	33653.766	33653.766	0.71	0.4006ns
	Spacing	2	164630.069	82315.035	1.74	0.1800ns
	Species*Spacing	2	11612.205	5806.103	0.12	0.8845ns
	Error	110	5198628.423	47260.258		
1999 (root system 5.5 coppice growth 1)	Block	4	137285.2759	34321.3190	0.87	0.4841ns
	Species	1	18096.6295	18096.6295	0.46	0.4995ns
	Spacing	2	68993.0384	34496.5192	0.88	0.4198ns
	Species*Spacing	2	45072.9062	22536.4531	0.57	0.5662ns
	Error	95	3741000.384	39378.951		
2000 (root system 6.5 coppice growth 2)	Block	4	1755065.088	438766.272	9.53	<.0001***
	Species	1	32469.339	32469.339	0.71	0.4029ns
	Spacing	2	330230.788	165115.394	3.59	0.0310*
	Species*Spacing	2	134489.579	67244.789	1.46	0.2366ns
	Error	110	5065600.896	46050.917		

ns = not significant p>0.05; * significant p≤0.05; ***highly significant p≤0.001

Table 7 Analysis of variance mean tree leaf yield (kg) as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	328.4771448	82.1192862	26.32	<.0001***
	Species	1	102.6769580	102.6769580	32.90	<.0001***
	Spacing	2	3.3796143	1.6898072	0.54	0.5682ns
	Species*Spacing	2	0.7233966	0.5616983	0.12	0.8807ns
	Error	109	340.1424829	3.1205732		
1998 (root system 4.5 coppice growth 2)	Block	4	2.60250333	0.65062583	2.56	0.0428***
	Species	1	0.23144083	0.23144083	0.91	0.3424ns
	Spacing	2	0.3978600	0.19893000	0.78	0.4603ns
	Species*Spacing	2	0.32600667	0.16300333	0.64	0.5291ns
	Error	110	28.00392167	0.25458111		
2000 (root system 6.5 coppice growth 2)	Block	4	172.6691583	43.1672896	12.67	<.0001***
	Species	1	4.4506008	4.4506008	1.31	0.2556ns
	Spacing	2	4.0365150	2.0182575	0.59	0.5548ns
	Species*Spacing	2	5.4286617	2.7143308	0.80	0.4534ns
	Error	110	374.7883767	3.4071671		

ns =n ot significant p>0.05; ***highly significant p≤0.001

Table 8 Analysis of variance mean tree pod yield (kg) as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	543.5554883	135.8888721	33.14	<.0001***
	Species	1	55.3928408	55.3928408	13.51	0.0004***
	Spacing	2	5.9945717	2.9972858	0.73	0.4837ns
	Species*Spacing	2	8.6016717	4.3008358	1.05	0.3538ns
	Error	110	450.999687	4.099997		
1998 (root system 4.5 coppice growth 2)	Block	4	1.82288788	0.45572197	0.29	0.8813ns
	Species	1	10.74258987	10.74258987	6.93	0.0098***
	Spacing	2	7.02782759	3.51391379	2.27	0.1090ns
	Species*Spacing	2	4.33450190	2.16725095	1.40	0.2520ns
	Error	100	155.0586213	1.5505862		
2000 (root system 6.5 coppice growth 2)	Block	4	187.0174516	46.7543629	6.81	<.0001***
	Species	1	279.4023422	279.4023422	40.71	<.0001***
	Spacing	2	144.0734958	72.0367479	10.49	<.0001***
	Species*Spacing	2	0.3631418	0.1815709	0.03	0.9739ns
	Error	117	1355.614390	6.863941		

ns = not significant p>0.05; ***highly significant p≤0.001

Table 9 Analysis of variance mean tree wood yield (kg) as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	3953.730122	988.432530	35.96	<.0001***
	Species	1	149.901453	149.901453	5.45	0.0213*
	Spacing	2	82.910535	41.455267	1.51	0.2258ns
	Species*Spacing	2	139.173952	69.586976	2.53	0.0842ns
	Error	110	3023.506218	27.486420		
1998 (root system 4.5 coppice growth 2)	Block	4	1118.587233	279.646808	7.34	<.0001***
	Species	1	3.162253	3.162253	0.08	0.7738ns
	Spacing	2	242.372072	121.186036	3.18	0.0454*
	Species*Spacing	2	134.894072	67.447036	1.77	0.1750ns
	Error	110	4190.216837	38.092880		
2000 (root system 6.5 coppice growth 2)	Block	4	1949.307838	487.326960	12.56	<.0001***
	Species	1	202.982041	202.982041	5.23	0.0241*
	Spacing	2	323.702822	161.851411	4.17	0.0179*
	Species *Spacing	2	93.929682	46.964841	1.21	0.3019ns
	Error	110	4266.332577	38.784842		

ns = not significant p>0.05; *significant p≤0.05; *** highly significant p≤0.001

Table 10 Analysis of variance mean tree total biomass (kg) as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (root system2.5)	Block	4	6561.574630	1640.393657	35.59	<.0001***
	Species	1	500.861880	500.861880	10.87	0.0013***
	Spacing	2	112.542327	56.271163	1.22	0.2989ns
	Species*Spacing	2	160.324580	80.162290	1.74	0.1804ns
	Error	110	5069.68733	46.08807		
1998 (root system 4.5 coppice growth 2)	Block	4	1250.661628	312.665407	6.19	0.0002***
	Species	1	4.466021	4.466021	0.09	0.7667ns
	Spacing	2	351.711312	175.855656	3.48	0.0341*
	Species*Spacing	2	191.799882	95.89941	1.90	0.1545ns
	Error	110	5553.260157	50.484183		
2000 (root system 6.5 coppice growth 2)	Block	4	3219.841908	804.960477	12.40	<.0001***
	Species	1	229.246163	229.246163	3.53	0.0628ns
	Spacing	2	469.219387	234.609693	3.61	0.0302*
	Species*Spacing	2	186.118427	93.059213	1.43	0.2428ns
	Error	110	7139.92578	64.90842		

ns = not significant p>0.05; *significant p≤0.05; ***statistically significant p≤0.001

Table 11 Analysis of variance mean leaf yield tonnes ha^{-1} as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	60540122.59	15135030.60	29.34	<.0001***
	Species	1	5676415.05	5676415.05	11.00	<.0001***
	Spacing	2	10259045.75	5129522.87	9.94	0.0003***
	Species*Spacing	2	990619.37	495309.68	0.96	0.3860ns
	Error	110	44.2737675	0.4024888		
1998 (root system 4.5 coppice growth 2)	Block	4	0.31824688	0.07956172	2.72	0.0334*
	Species	1	0.01776333	0.01776333	0.61	0.4378s
	Spacing	2	0.07054047	0.03527023	1.20	0.3039ns
	Species*Spacing	2	0.03536287	0.01768143	0.60	0.5291ns
	Error	110	3.22198992	0.02929082		
2000 (root system 6.5 coppice growth 2)	Block	4	17.33217387	4.33304347	12.03	<0001***
	Species	1	0.57893521	0.57893521	1.61	0.2076ns
	Spacing	2	1.70907962	0.85453981	2.37	0.0980ns
	Species*Spacing	2	0.56100902	0.28050451	0.78	0.4615ns
	Error	110	39.62338028	0.36021255		

ns = not significant p>0.05; *significant p≤0.05; ***statistically significant p≤0.001

Table 12 Analysis of variance mean pod yield tonnes ha^{-1} as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	60.54555437	15.13638859	29.34	<.0001***
	Species	1	5.67631501	5.67631501	11.00	0.0012***
	Spacing	2	10.25862582	5.12931291	9.94	0.0001***
	Species*Spacing	2	0.99018042	0.49509021	0.96	0.3862ns
	Error	110	56.7441364	0.5158558		
1998 (root system 4.5 coppice growth 2)	Block	4	0.16156387	0.04039097	0.33	0.8599ns
	Species	1	1.48585508	1.48585508	12.00	0.0008***
	Spacing	2	0.12681605	0.06340803	0.51	0.6007ns
	Species*Spacing	2	0.69776835	0.34888418	2.82	0.0641ns
	Error	110	113.62398498	0.12385441		
2000 (root system 6.5 coppice growth 2)	Block	4	19.22757122	4.80689280	7.76	<.0001***
	Species	1	28.45930601	28.45930601	45.94	<.0001***
	Spacing	2	2.95950882	1.47975441	2.39	0.0965ns
	Species*Spacing	2	1.17493462	0.58746731	0.95	0.3906ns
	Error	110	68.1479349	0.6195267		

ns = not significant p>0.05; ***statistically significant p≤0.001

Table 13 Analysis of variance mean wood yield tonnes ha^{-1} as a source of variation (DF=1)

Year (Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	445.0649762	111.2662441	32.31	0<0001***
	Species	1	14.1501404	14.1501404	4.11	0.0451*
	Spacing	2	67.2705290	33.6352645	9.77	0.0001***
	Species*Spacing	2	14.3620597	7.1810299	2.08	0.1292ns
	Error	110	378.8591977	3.4441745		
1998 (root system 4.5 coppice growth 2)	Block	4	133.6507796	33.4126949	8.39	<.0001***
	Species	1	0.6670734	0.6670734	0.17	0.6831ns
	Spacing	2	5.4026041	2.7013021	0.68	0.5096ns
	Species*Spacing	2	4.2118903	2.1059452	0.53	0.5908ns
	Error	110	438.0902788	3.9826389		
2000 (root system 6.5 coppice growth 2)	Block	4	187.3630910	46.8407728	12.47	<.0001***
	Species	1	25.3726837	25.3726837	6.75	0.0106*
	Spacing	2	1.2558456	0.6279228	0.17	0.8463ns
	Species*Spacing	2	13.4190907	6.7095453	1.79	0.1725ns
	Error	110	413.3116573	3.7573787		

ns = not significant p>0.05; * significant p≤0.05; ***statistically significant p≤0.001

Table 14 Analysis of variance mean total biomass tonnes ha^{-1} as a source of variation (DF=1)

Year Age in years)	Source	DF	Type III SS	MS	F-value	p-value
1996 (2.5)	Block	4	1218.580212	304.645053	32.48	<.0001***
	Species	1	87.859853	87.859853	9.37	0.0028***
	Spacing	2	196.469569	98.234784	10.47	<.0001***
	Species*Spacing	2	24.823547	12.411773	1.32	0.2704ns
	Error	110	1031.595311	9.378139		
1998 (root system 4.5 coppice growth 2)	Block	4	147.8789081	36.9697270	7.21	<.0001***
	Species	1	4.7052720	4.7052720	0.92	0.3402ns
	Spacing	2	5.2049521	2.6024761	0.51	0.6033ns
	Species*Spacing	2	8.0017253	4.0008627	0.78	0.4608ns
	Error	110	563.9504444	5.1268222		
2000 (root 6.5 coppice growth 2)	Block	4	478.2333464	119.5583366	12.74	<.0001***
	Species	1	123.9540460	123.9540460	13.21	0.0004***
	Spacing	2	8.5203625	4.2601813	0.45	0.6362ns
	Species*Spacing	2	29.5183988	14.7591994	1.57	0.2120ns
	Error	110	1032.092952	9.382663		

ns = not significant $p>0.05$; ***statistically significant $p\leq0.001$

Table 15 Correlation coefficients of *L. diversifolia* and *L. leucocephala* at different stages of the study.

Parameter	*L. diversifolia*						*L. Leucocephala*					
Cd &	1994	1995	1996	1998	1999	2000	1994	1995	1996	1998	1999	2000
Stno	0.14734ns	0.5651***	0.5697***	0.4577***	0.8906***	0.7112***	0.3747***	0.6504***	0.7182***	0.6996***	0.8371***	0.7391***
Mstd	-	0.4167***	0.6479***	0.7493***	0.8347***	0.7234***	-	0.7122***	0.6891***	0.6596***	0.8107***	0.7860***
Lfw	-	-	0.6467***	0.7392***	-	0.8327***	-	-	0.5444***	0.6373***	-	0.8609***
Pods	-	-	0.637***	0.1918ns	-	0.5757***	-	-	0.4967***	0.2078ns	-	0.6896***
Wd	-	-	0.6293***	0.8365***	-	0.8426***	-	-	0.5254***	0.8210***	-	0.8565***
Ht	0.6885***	0.1157ns	-0.1112ns	0.7841***	0.8192***	0.7194***	0.8138***	0.3485**	0.1885ns	0.7956***	0.8713***	0.8713***
Svi	-	0.662***	0.5524***	0.9062***	0.1034ns	0.8530***	-	0.8498***	0.7956***	0.8272***	0.8443***	0.8257***
Stno &												
Mstd	-	-0.0552ns	0.1966ns	0.1333ns	0.8056***	0.2607*	0.1473ns	0.1569ns	0.2652*	0.1838ns	0.5624***	0.4695***
Lfw	-	-	0.5069***	0.4207**	-	0.7024***	-	-	0.5744***	0.6868***	-	0.7586***
Pods	-	-	0.5565***	-0.0972ns	-	0.5470***	-	-	0.5336***	0.3423**	-	0.6138***
Wd	-	-	0.5523***	0.4069**	-	0.6767***	-	-	0.6584***	0.7716***	-	0.7834***
Ht	-0.0114ns	0.2063ns	0.0841ns	0.4207***	0.8230***	0.3992***	0.3722***	0.1933ns	0.1005ns	0.6077***	0.7795***	0.7430***
Svi	-	0.7409***	0.4525***	0.4067***	0.0821ns	0.7020***	-	0.5653***	0.7338***	0.7186***	0.9056***	0.7340***
Mstd &												
Lfw	-	-	0.4675***	0.5891***	-	0.7108***	-	-	0.3345**	0.03626**	-	0.7634***
Pods	-	-	0.3732**	0.2149ns	-	0.5269***	-	-	0.3400**	0.0778ns	-	0.6550***
Wd	-	-	0.4250***	0.7229***	-	0.7538***	-	-	0.3383**	0.4926***	-	0.7429***
Ht	-	0.0853ns	0.1116***	0.6488***	0.9083***	0.7650***	-	0.2988*	0.3508**	0.7032***	0.8080***	0.7141***
Svi	-	0.53122***	0.8111***	0.8427***	0.9106***	0.7569***	-	0.7750***	0.7409***	0.7191***	0.6855***	0.8078***
Lfw &												
Pods	-	-	0.9276***	0.2964*	-	0.5774***	-	-	0.8661***	0.1915***	-	0.6506***
Wd	-	-	0.9738***	0.8204***	-	0.9481***	-	-	0.8946***	0.8222***	-	0.9591***
Ht	-	-	-0.1143ns	0.7045***	-	0.6401***	-	-	0.2699*	0.5921***	-	0.8334***
Svi	-	-	0.5086***	0.7508***	-	0.9012***	-	-	0.5261***	0.6686***	-	0.8834***
Pods &												
Wd	-	-	0.9234***	0.3595**	-	0.7191***	-	-	0.8916***	0.3770**	-	0.7018***
Ht	-	-	-0.1828ns	0.069ns	-	0.5567***	-	-	0.3633**	0.3464**	-	0.6228***
Svi	-	-	0.4445***	0.2352ns	-	0.7357***	-	-	0.5751***	0.2493ns	-	0.6579***
Wd &												
Ht	-	-	-0.0798ns	0.6655***	-	0.7266***	-	-	0.3294***	0.6955***	-	0.8441***
Svi	-	-	0.4846***	0.8387***	-	0.9688***	-	-	0.5877***	0.7901***	-	0.9109***
Ht &												
Svi	-	-	0.153ns	0.7153***	-	0.8116***	-	0.3990**	0.4251***	0.8083***	0.7688***	0.8547***

ns = not significant p>0.05; * significant p≤0.05; **significant p≤0.01; ***statistically significant p≤0.001.

Cd=crown: Stno=mean stem number;Mstd=mean stem diameter; Lfw=leaf mass; Pods= pod mass; Wd = woodmass; Ht = mean tree height; Svi = Mean stem volume index

APPENDIX 6: ANOVA SUMMARY TABLES FOR BROWSE NUTRITION

Table 1 Analysis of variance nutritional composition of leaves with species as source of variation (DF=3)

Parameter	Source	DF	Anova SS	MS	F-value	p_value
ADF	Block	4	1126.93065	281.73664	20.78	<.0001***
	Species	3	3164.72646	1054.90882	77.80	<.0001***
	Spacing	2	103.830098	51.915049	3.83	0.0231*
	Species*Spacing	6	1831.534731	305.255789	0.57	0.6813ns
	Runs	4	31.168855	7.792214	22.51	<.0001***
	$Error_1$	44	9685.351753	220.121631	16.23	<.0001***
	$Error_2$	236	3200.11506	13.55981		
ADL	Block	4	876.153575	219.038394	29.17	<.0001***
	Species	3	1909.97628	636.658763	84.78	<.0001***
	Spacing	2	20.008933	10.004466	1.33	0.2659ns
	Runs	4	29.589169	7.397292	0.99	0.4164ns
	Species*Spacing	6	558.811254	93.135209	12.40	<.0001***
	$Error_1$	44	4645.962009	105.590046	14.06	<.0001***
	$Error_2$	236	1772.266791	7.5090605		
Ash	Block	4	46.8152833	11.7038208	37.38	<.0001***
	Species	3	309.6111583	103.2037194	329.57	<.0001***
	Spacing	2	1.3685167	0.6842583	2.19	0.1147ns
	Runs	4	2.9148667	0.7287167	2.33	0.0570ns
	Species*Spacing	6	33.4216167	5.5702694	17.79	<.0001***
	$Error_1$	44	146.0459167	3.3192254	10.60	<.0001***
	$Error_2$	236	73.9021333	0.3131446		
CP	Block	4	1686.118985	421.529746	77.05	<.0001***
	Species	3	3733.874732	1244.624911	227.49	<.0001***
	Spacing	2	11.558648	5.779324	1.06	0.3494ns
	Runs	4	24.814779	6.203695	1.13	0.3412ns
	Species*Spacing	6	94.969021	15.828170	2.89	0.0097**
	$Error_1$	44	1573.309871	35.757043	6.54	<.0001***
	$Error_2$	236	1291.185621	5.471126		
IVDMD	Block	4	224.736631	56.184158	13.87	<.0001***
	Species	3	2496.279166	832.093055	205.48	<.0001***
	Spacing	2	23.792198	11.896099	2.94	0.0549ns
	Runs	4	24.312175	6.078044	1.50	0.2026ns
	Species*Spacing	6	208.80340	34.800567	8.59	<.0001***
	$Error_1$	44	1999.126713	45.434698	11.22	<.0001***
	$Error_2$	236	955.705945	4.049601		
NDF	Block	4	2738.693408	684.673352	34.65	<.0001***
	Species	3	550.113395	183.371132	9.28	<.0001***
	Spacing	2	42.022993	21.011496	1.06	0.3469ns
	Runs	4	75.505988	18.876497	0.96	0.4328ns
	Species*Spacing	6	209.941839	34.990307	1.77	0.1058ns
	$Error_1$	44	4060.150200	92.276141	4.67	<.0001***
	$Error_2$	236	4663.07521	19.75879		
OM	Block	4	44.1153833	11.0288458	34.40	<.0001***
	Species	3	300.714891	100.238297	312.61	<.0001***
	Spacing	2	1.8338167	0.9169083	2.86	0.0593ns
	Runs	4	3.1823000	0.7955750	2.48	<.0001***
	Species*Spacing	6	33.6153833	5.6025639	17.47	<.0001***
	$Error_1$	44	144.3186167	3.2799686	10.23	<.0001***
	$Error_2$	236	75.6727000	0.3206470		
Tannin	Block	4	42.8055813	10.7013953	52.23	<.0001***
	Species	3	2.88448100	0.96149367	4.69	0.0033***
	Spacing	2	0.02851267	0.01425633	0.07	0.9328ns
	Runs	4	0.5948547	0.1487137	0.73	0.5751ns
	Species*Spacing	6	29.5207620	4.92012700	24.01	<.0001***
	$Error_1$	44	161.8075627	3.6774446	17.95	<.0001***
	$Error_2$	236	48.3536253	0.2048882		

ns = not significant $p>0.05$; *significant $p\leq0.05$; ***statistically significant $p\leq0.001$

Table 2 Analysis of variance mineral composition of leaves with species as a source of variation (D = 3)

Parameter	Source	DF	Anova SS	MS	F-value	p-value
Ca	Block	4	3.76307133	0.9407683	29.76	<.0001***
	Species	3	17.660676	5.88689200	186.23	<.0001***
	Spacing	2	3.95767267	1.97883633	62.60	<.0001***
	Runs	4	0.02862800	0.00715700	0.23	0.9235ns
	Species*Spacing	6	3.67083400	0.61180567	19.35	<.0001***
	$Error_1$	44	31.81312067	0.72302547	22.87	<.0001***
	$Error_2$	236	7.46021200	0.03161107		
Mg	Block	4	0.49693667	0.12423417	60.62	<.0001***
	Species	3	6.06305200	2.02101733	986.18	<.0001***
	Spacing	2	0.01105800	0.00552900	2.70	0.0694ns
	Runs	4	0.01451667	0.00362917	1.77	0.1354ns
	Species*Spacing	6	0.578254	0.9637567	47.03	<.0001***
	$Error_1$	44	3.86623933	0.08786908	42.88	<.0001***
	$Error_2$	236	0.48364333	0.00204934		
K	Block	4	10.8336113	2.70840283	142.44	<.0001***
	Species	3	0.82195300	0.27398433	14.41	<.0001***
	Spacing	2	1.02492200	0.51246100	26.95	<.0001***
	Runs	4	0.01808800	0.00452200	0.24	0.9168ns
	Species*Spacing	6	2.690206	0.44836767	23.58	<.0001***
	$Error_1$	44	27.75862067	0.63087774	33.18	<.0001***
	$Error_2$	236	4.48739200	0.01901437		
Na	Block	4	0.00041608	0.00010427	1301.43	<.0001***
	Species	3	0.00000849	0.00000283	35.32	<.0001***
	Spacing	2	0.00000202	0.00000101	12.63	<.0001***
	Runs	4	0.00000059	0.00000015	1.83	0.1234ns
	Species*Spacing	6	0.00001351	0.00000225	28.10	<.0001***
	$Error_1$	44	0.00021173	0.00000481	60.06	<.0001***
	$Error_2$	236	0.00001891	0.00000008		
P	Block	4	0.62506133	0.15626533	149.81	<.0001***
	Species	3	0.21607300	0.07202433	69.05	<.0001***
	Spacing	2	0.00145267	0.00072633	0.70	0.4994ns
	Runs	4	0.01787800	0.00446950	4.28	0.0023***
	Species*Spacing	6	0.059494	0.00991567	9.51	<.0001***
	$Error_1$	44	0.55713867	0.01266224	12.14	<.0001***
	$Error_2$	236	0.24616200	0.00104306		

ns = not significant $p>0.05$; ***statistically significant $p\leq0.001$

Table 3. Analysis of variance nutritional comparision of leaves and pods of *L. diversifolia* (DF=1)

Parameter	Source	DF	Anova SS	MS	F-value	p-value
ADF	Block	4	816.033491	204.008373	16.31	<.0001***
	Spacing	2	348.612609	174.306305	13.93	<.0001***
	Part	1	837.376321	837.376321	66.94	<.0001***
	Runs	4	44.239104	11.05776	0.88	0.4758ns
	Spacing *part	2	1270.411649	635.205825	50.78	<.0001***
	$Error_1$	20	4547.826477	227.391324	18.18	<.0001***
	$Error_2$	116	1451.125296	12.509701		
ADL	Block	4	250.803520	62.700880	13.00	<.0001***
	Spacing	2	292.639228	146.319614	30.33	<.0001***
	Part	1	1.50000	1.500000	0.31	0.5782ns
	Runs	4	6.580627	1.645157	0.34	0.8498ns
	Spacing *part	2	243.055372	121.527686	25.19	<.0001***
	$Error_1$	20	1415.44300	70.772150	14.67	<.0001***
	$Error_2$	116	559.683053	4.824854		
Ash	Block	4	21.03488933	5.2582233	7.16	<.0001***
	Spacing	2	17.98193067	8.61625400	11.74	<.0001***
	Part	1	18.98193067	18.98193067	25.85	<.0001***
	Runs	4	4.79180267	1.19795067	1.63	0.1710ns
	Spacing *part	2	5.84124133	2.92062067	3.98	0.0213*
	$Error_1$	20	58.28708667	2.91435433	3.97	<.0001***
	$Error_2$	116	85.1688773	0.7342145		
CP	Block	4	742.6573240	185.6643310	80.85	<.0001***
	Spacing	2	10.8377440	5.4188720	2.36	0.0990ns
	Part	1	59.3209927	59.3209927	25.83	<.0001***
	Runs	4	20.9925240	5.2481310	2.29	0.0643ns
	Spacing *part	2	35.2596853	17.6298427	7.68	0.0007***
	$Error_1$	20	299.0417080	14.9520854	6.51	<.0001***
	$Error_2$	116	266.375356	2.296339		
INVTD	Block	4	180.522737	45.130684	8.30	<.0001***
	Spacing	2	43.856549	21.928275	4.03	0.0203*
	Part	1	1801.349574	1801.349574	331.18	<.0001***
	Runs	4	36.722337	9.180584	1.69	0.1575ns
	Spacing *part	2	280.322224	140.161112	25.77	<.0001***
	$Error_1$	20	1130.370383	56.518519	10.39	<.0001***
	$Error_2$	116	630.947583	5.439203		
NDF	Block	4	873.955060	218.488765	16.61	<.0001***
	Spacing	2	179.839164	89.910582	6.83	0.0016***
	Part	1	423.662454	423.662454	32.20	<.0001***
	Runs	4	14.924267	3.731067	0.28	<.0001***
	Spacing *part	2	31.100628	15.550314	1.18	0.8881ns
	$Error_1$	20	2856.716324	142.835816	10.86	<.0001***
	$Error_2$	116	1526.218453	13.157056		
OM	Block	4	20.46022267	5.11505567	6.95	<.0001***
	Spacing	2	20.23778800	10.11889400	13.74	<.0001***
	Part	1	16.24273067	16.24273067	22.06	<.0001***
	Runs	4	4.19740267	1.04935067	1.42	0.2301ns
	Spacing *part	2	4.91772133	2.45886067	3.34	0.0389*
	$Error_1$	20	60.50799333	3.02539967	4.11	<.0001***
	$Error_2$	116	85.4232773	0.7364076		
Tannin	Block	4	18.02358933	4.505089733	29.25	<.0001***
	Spacing	2	18.98898533	9.49449267	61.64	<.0001***
	Part	1	4.20341400	4.20341400	27.29	<.0001***
	Runs	4	0.17436933	0.04359233	0.28	0.8885ns
	Spacing *part	2	0.11018800	0.05509400	0.36	<.7001ns
	$Error_1$	20	98.3570267	4.91787013	31.93	<.0001***
	$Error_2$	116	17.8669107	0.1540251		

ns = not significant $p>0.05$; *significant $p\leq0.05$; ***statistically significant $p\leq0.001$

Table 4 Analysis of variance nutritional comparison leaves and pods of *L. leucocephala* (DF=1)

Parameter	Source	DF	Anova SS	MS	F-value	p-value
ADF	Block	4	980.66043	245.165011	30.31	<.0001***
	Spacing	2	441.796709	220.898355	27.31	<.0001***
	Part	1	779.623206	779.623206	96.39	<.0001***
	Runs	4	19.312609	4.828152	0.60	0.6656ns
	Spacing *part	2	368.693136	184.346568	22.79	<.0001***
	$Error_1$	20	3858.422325	192.921116	23.85	<.0001***
	$Error_2$					
ADL	Block	4	1071.878569	267.969642	36.41	<.0001***
	Spacing	2	91.416809	45.708405	6.21	<.0027***
	Part	1	18.981931	18.981931	2.58	0.1110ns
	Runs	4	69.641776	17.410444	2.37	0.0.569
	Spacing *part	2	42.108305	21.054153	2.86	0.0613ns
	$Error_1$	20	681.038415	34.051921	4.63	<.0001***
	$Error_2$					
Ash	Block	4	22.8697333	5.7174333	128.35	<.0001***
	Spacing	2	7.3008333	3.6504167	81.95	<.0001***
	Part	1	78.4093500	78.4093500	1760.21	<.0001***
	Runs	4	0.0207333	0.0051833	0.12	0.9765ns
	Spacing *part	2	2.6875000	1.3437500	30.17	<.0001***
	$Error_1$	20	111.5130667	5.5756533	125.17	<.0001***
	$Error_2$					
CP	Block	4	895.6366707	223.9091677	85.20	<.0001***
	Spacing	2	19.8415573	9.9207787	3.78	0.0258*
	Part	1	256.0282727	256.0282727	97.43	<.0001***
	Runs	4	5.6460173	1.4115043	0.54	0.7087ns
	Spacing *part	2	18.6119093	9.3059547	3.54	0.0322*
	$Error_1$	20	650.3207373	32.5160369	12.37	<.0001***
	$Error_2$					
INVTD	Block	4	361.224571	90.306143	15.37	<.0001***
	Spacing	2	65.427484	32.713742	5.57	0.0049***
	Part	1	2965.393091	2965.393091	504.69	<.0001***
	Runs	4	58.543451	14.635863	2.49	0.0469*
	Spacing *part	2	10.609417	5.304709	0.90	0.4083ns
	$Error_1$	20	594.189261	29.709463	5.06	<.0001***
	$Error_2$					
NDF	Block	4	919.2237	229.805946	16.47	<.0001***
	Spacing	2	19.166201	9.583101	0.69	0.5052ns
	Part	1	687.839094	687.839094	49.30	<.0001***
	Runs	4	50.904629	12.726157	0.91	0.4594ns
	Spacing *part	2	44.244844	22.122422	1.59	0.2092ns
	$Error_1$	20	2211.108737	110.555437	7.92	<.0001***
	$Error_2$					
OM	Block	4	20.3536000	50884000	100.87	<.0001***
	Spacing	2	7.7120333	3.8560167	76.44	<.0001***
	Part	1	75.8281500	75.8281500	1503.16	<.0001***
	Runs	4	0.0982667	0.0245667	0.49	0.7453ns
	Spacing *part	2	2.3167000	1.15835000	22.96	<.0001***
	$Error_1$	20	107.8872000	5.3943600	106.93	<.0001***
	$Error_2$					
Tannin	Block	4	98.04814267	24.51203567	198.52	<.0001***
	Spacing	2	5.35092133	2.67546067	21.67	<.0001***
	Part	1	0.70864067	0.70864067	5.74	0.0182*
	Runs	4	0.24408933	0.06102233	0.49	0.7400ns
	Spacing *part	2	9.17130533	4.58565267	37.14	<.0001***
	$Error_1$	20	74.02356933	3.70117847	29.98	<.0001***
	$Error_2$					

ns = not significant $p>0.05$; *significant $p\leq0.05$; ***statistically significant $p\leq0.001$

Table 5 Analysis of variance Mineral Comparison of leaves and pods of *L. diversifolia*

Parameter	Source	DF	Anova SS	MS	F-value	p-value
Ca	Block	4	1.8284400	0.45713600	10.08	<.0001***
	Spacing	2	0.15357733	0.07678867	1.69	0.1883ns
	Part	1	12.39556267	12.39556267	273.46	<.0001***
	Runs	4	0.13289067	0.03322267	0.73	0.5713ns
	Spacing *part	2	0.27658533	0.13829267	3.05	0.0511ns
	$Error_1$	20	7.82616800	0.39130840	8.63	<.0001***
	$Error_2$	116	5.25818933	0.04532922		
Mg	Block	4	0.12373333	0.03093333	20.47	<.0001***
	Spacing	2	0.04990533	0.02495267	16.52	<.0001***
	Part	1	0.35917067	0.35917067	237.73	<.0001***
	Runs	4	0.00242000	0.00060500	0.40	0.8080ns
	Spacing *part	2	0.03744133	0.01872067	12.39	<.0001***
	$Error_1$	20	1.31980267	0.06599013	43.68	<.0001***
	$Error_2$	116	0.17526000	0.00151086		
K	Block	4	4.18348933	1.04587233	165.80	<.0001***
	Spacing	2	0.56979733	0.28489867	45.16	<.0001***
	Part	1	1.28806667	1.28806667	204.19	<.0001***
	Runs	4	0.02744933	0.00686233	1.09	0.3659ns
	Spacing *part	2	1.50419733	0.75209867	119.23	<.0001***
	$Error_1$	20	15.89851867	0.79492593	126.01	<.0001***
	$Error_2$	116	0.73175067	0.00630820		
Na	Block	4	0.00029273	0.00007318	151.01	<.0001***
	Spacing	2	0.00000085	0.00000042	0.87	0.4203ns
	Part	1	0.00004363	0.00004363	90.04	<.0001***
	Runs	4	0.00000242	0.00000060	1.25	0.2951ns
	Spacing *part	2	0.00000387	0.00000193	3.99	0.0211*
	$Error_1$	20	0.00005283	0.00000264	5.45	<.0001***
	$Error_2$	116	0.00005621	0.00000048		
P	Block	4	0.26362667	0.06590667	127.82	<.0001***
	Spacing	2	0.01811733	0.00905867	17.57	<.0001***
	Part	1	0.10773600	0.10773600	208.94	<.0001***
	Runs	4	0.00162667	0.00040667	0.79	0.5348ns
	Spacing *part	2	0.01451200	0.00725600	14.07	<.0001***
	$Error_1$	20	0.23090133	0.01154507	22.39	<.0001***
	$Error_2$	116	0.05981333	0.00051563		

ns = not significant $p>0.05$; ***statistically significant $p\leq0.001$

Table 6 Analysis of variance mineral comparison of leaves and pods of *L. leucocephala*

Parameter	Source	DF	Anova SS	MS	F-value	p-value
Ca	Block	4	1.49064400	0.37266100	46.52	<.0001***
	Spacing	2	1.11550533	0.5577267	69.63	<.0001***
	Part	1	9.78948267	9.78948267	1222.12	<.0001***
	Runs	4	0.00801067	0.00200267	0.25	0.9091ns
	Spacing *part	2	1.34234533	0.67117267	83.79	<.0001***
	$Error_1$	20	11.72758000	0.58637900	73.20	<.0001***
	$Error_2$					
Mg	Block	4	0.15903600	0.03975900	44.03	<.0001***
	Spacing	2	0.01474133	0.00737067	8.16	<.0005***
	Part	1	2.89537067	2.89537067	3206.31	<.0001***
	Runs	4	0.00160933	0.00040233	0.45	0.7754ns
	Spacing *part	2	0.38736533	0.19368267	214.48	<.0001***
	$Error_1$	20	1.38343600	0.06917180	76.60	<.0001***
	$Error_2$					
K	Block	4	2.92309733	0.73077433	68.34	<.0001***
	Spacing	2	0.78643600	0.39321800	36.77	<.0001***
	Part	1	0.02041667	0.02041667	1.91	<.1697ns
	Runs	4	0.03403733	0.00850933	0.80	0.5303ns
	Spacing *part	2	0.30929733	0.15464867	14.46	<.0001***
	Error	20	15.21152667	0.76057633	71.13	<.0001***
Na	Block	4	0.00037159	0.00009290	1299.53	<.0001***
	Spacing	2	0.00000013	0.00000007	0.93	0.3976ns
	Part	1	0.00001634	0.00001634	228.51	<.0001***
	Runs	4	0.00000032	0.00000008	1.10	0.35821ns
	Spacing *part	2	0.00000385	0.00000193	26.95	<.0001***
	$Error_1$	20	0.00003998	0.00000200	27.96	<.0001***
	$Error_2$					
P	Block	4	0.13512000	0.03378000	23.98	<.0001***
	Spacing	2	0.02654800	0.01327400	9.42	<.0001***
	Part	1	0.16269067	0.16269067	115.47	<.0001***
	Runs	4	0.00312000	0.00078000	0.55	0.5348ns
	Spacing *part	2	0.04620933	0.02310467	16.40	<.0001***
	$Error_1$	20	0.22687200	0.01134360	8.05	<.0001***
	$Error_2$					

ns = not significant $p>0.05$; ***statistically significant $p\leq0.001$

APPENDIX 7: ANOVA SUMMARY TABLE FOR MASS GAIN OF LAMBS

Table 1 Analysis of variance mean mass of lambs over time with feed as a source of variance (DF=1)

Time (days)	Treatment	CV	MSS	F-value	p-value
0	Bran 16.00 ± 0.79 Browse 16.04 ± 0.53	11.88908	0.005625	0.00	0.9691ns
14	Bran 18.50 ± 0.61 Browse 18.81 ± 0.61	9.280570	0.39062500	0.13	0.7235ns
21	Bran 19.62 ± 0.65 Browse 19.00 ± 0.62	9.321929	1.5625	0.48	0.4988ns
28	Bran 19.62 ± 0.82 Browse 20.14 ± 0.51	9.717421	1.050625	0.28	0.6040ns
35	Bran 19.52 ± 0.59 Browse 20.62 ± 0.59	8.293775	4.84	1.75	0.2076ns
49	Bran 20.06 ± 0.69 Browse 22.75 ± 0.81	9.966187	28.890625	6.35	0.0245*
56	Bran 21.44 ± 0.10 Browse 24.06 ± 0.94	12.03428	27.5625	3.68	0.758ns
70	Bran 23.87 ± 1.05 Browse 25.87 ± 1.25	13.10392	16.0000	1.51	0.2400ns
77	Bran 23.75 ± 1.26 Browse 26.00 ± 0.75	11.84298	20.25000	2.33	0.1489ns
84	Bran 20.62 ± 1.32 Browse 24.87 ± 1.65	18.62120	72.25000	4.03	0.0645ns
98	Bran 23.50 ± 1.43 Browse 28.12 ± 0.95	13.29485	85.5625	7.27	0.0174*
112	Bran 24.12 ± 1.35 Browse 27.94 ± 1.41	15.00497	58.14062	3.81	0.0712ns
134	Bran 27.25 ± 1.58 Browse 29.75 ± 0.59	11.82469	25.0000	2.20	0.1601ns

ns = not significant; *signifcant $p \leq 0.05$;